ASSESSING THE SUITABILITY OF COARSE POND ASH AND BOTTOM ASH AS FILTER MATERIAL

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CERTIFICATE

This is to certify that the thesis entitled "ASSESSING THE SUITABILITY OF COARSE POND ASH AND BOTTOM ASH AS FILTER MATERIAL" being submitted by BENAZEER SULTANA towards the fulfilment of the requirement for the degree of Master of Technology in Geotechnical Engineering at Department of Civil Engineering, NIT Rourkela is a record of bonfire work carried out by her under my guidance and supervision.

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SYNOPSIS

Energy requirements for the developing countries like India in particular are met from coal-based thermal power plants, where 75% of the total power obtained is from coal-based thermal power plants. The coal reserve of India is about 200 billion tonnes (bt) and its annual production reaches 250 million tonnes (mt) approximately. About 70% of this is used in the power sector. In India, unlike in most of the developed countries, ash content in the coal used for power generation is 30–40%. High ash coal means more generation of a large amount of fly ash. India ranks fourth in the world in the production of coal ash as by-product waste after USSR, USA and China, in that order. Huge amount of coal ash generation creates major problems for their disposal. Therefore large quantity coal ash has to be suitably disposed off.
Primarily, the coal ash is disposed off using either dry or wet disposal scheme. In dry disposal, the fly ash is transported by truck, chute, or conveyor at the site and disposed off by constructing a dry embankment (dyke). In wet disposal, the fly ash and bottom ash are transported as slurry through pipe and disposed off in pond ash. There are no well defined design guidelines and code practices available for construction and maintenance of ash dykes. So in past there are so many failures of ash dykes are observed. Main reason for failure of ash dyke is due to ineffective functioning of filter or internal drains. The purpose of filter in the case of ash dyke is to protect the fly ash against being carried away with seepage and at the same time it should have adequate permeability to take out the seepage water in order to keep the fly ash in a dry condition avoiding liquefaction due to any disturbance. Natural river sand is used as the conventional filter material. However, the non-availability of required graded sand in and around construction site and in all seasons possesses problems to the construction of ash dykes. Non-availability of good sand during monsoon also affects the sustained and pre-planned construction of ash dykes in monsoon season. Coarse pond ash and bottom ash which are the waste products of thermal power plant and non-plastic in nature and available abundantly in thermal power plants may replace the conventional sand as a filtering material.

Limited work has been reported in the literature on evaluation of the geotechnical properties of coal ash and their utilisation in filter media in ash pond dykes. This present work aims to find out the geotechnical properties of coal ash subjected to different loading intensity and its filter criteria. For this purpose coal ashes like bottom ash and coarse pond ash samples used in this study were collected from hopper and ash pond of NTPC, Kaniha, Odisha respectively.

Coarse sand was collected from Brahmini River whereas fly ash was collected from RSP, Rourkela. Coal ashes, coarse pond ash and bottom ash and sand were subjected to both dynamic and static compaction. Then for all the samples physical property, index properties, and geotechnical properties like grain size distribution, dry density, coefficient of permeability, crushing strength, strength parameters have been found out when samples were subjected to both dynamic and static compaction and also model test has been done to find out the filtering capabilities of these materials.

Based on the experimental findings the following conclusions are drawn. Specific gravity of pond ash and bottom ash are found to lower than that of conventional earth material. As the dynamic compaction energy and static stress increases, particles crushed. The gradation changes from uniformly graded to well grade. These samples show higher maximum dry density compare to virgin sample. After crushing due to both static and dynamic compaction, the coefficient of permeability of coal ash and sand samples decrease. Strength parameters of coal ashes and sand subjected higher compaction energy and static stress are found to be higher when tested at their minimum and maximum densities. At low load intensity crushing coefficient of coal ash is higher than sand but at very high load intensity crushing coefficient of sand is higher than coal ash. From the model test it was found that coefficient of permeability of all the virgin samples and layered samples decrease with increase in time due to settlement of fly ash slurry. After 60 min. values of coefficient of permeability of all samples are found to be same and do not change with time. So as per permeability criteria coarse pond ash and bottom ash can replace sand in filters. From the model test it was found that turbidity of all the virgin samples and layered samples decrease sharply with increase in time. It is found that coarse pond ash, bottom ash and sand used in the present study meets the filter criteria as per Indian standard of practice. After crushing in both static and dynamic compaction it is found that all three samples coarse pond ash, bottom ash and sand used in the present study meets the filter criteria as per Indian standard code of practice. Use of both coarse pond ash and bottom ash as a filter material also reduces the cost of construction of ash dyke. It is also an effective means of utilisation of thermal power plant waste.

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CHAPTER -1

INTRODUCTION

INTRODUCTION

Coal-based thermal power plants are the major source of power generation in India and coal ashes are the by-products of these thermal power plant. The coal reserve of India is about 200 billion tonnes and its annual production reaches 250 million tonnes approximately. In India, unlike in most of the developed countries, ash content in the coal used for power generation is about 30 to 40%. The ash generation has increased to about 131 million tonne during 2010-11and shall continue to grow. The finer ash particles are carried away by the flue gas to the electrostatic precipitators and are referred as fly ash, whereas the heavier ash particles fall to the bottom of the boiler and are called as bottom ash. Primarily, the fly ash is disposed off using either dry or wet disposal scheme. In dry disposal, the fly ash is transported by truck, chute or conveyor at the site and disposed off by constructing a dry embankment (dyke). In wet disposal, the fly ash and bottom ash are transported as slurry through pipe and disposed off in pond ash is called ash pond. Most of the power plants in India use wet disposal system, and when the lagoons are full, four basic options are available: (a) constructing new lagoons using conventional constructional material, (b) hauling of fly ash from the existing lagoons to another disposal site, (c) raising the existing dyke using conventional constructional material, and (d) raising the dyke using fly ash excavated from the lagoon ("ash dyke"). The option of raising the existing dyke is very cost effective because any fly ash used for constructing dyke would, in addition to saving the earth filling cost, enhance disposal capacity of the lagoon. The constructional methods for an ash dyke can be grouped into three broad categories: (a) Upstream method, (b) Downstream method and (c) Centreline method. At present around 265 km^2 of area is covered by ash ponds and as per the World Bank scenario, India by the year of 2015, disposal of coal ash would require 1000 square kilo meters or 1 square meter of land per person. The construction procedure of an ash dyke includes surface treatment of lagoon ash, spreading and compaction, benching, and soil cover. Since coal currently accounts for 75% of power production in the country, the bank has highlighted the need for new and innovative methods for reducing impact on the environment. The scarcity of land most often forces the power plants to raise the dykes to increase the ponding capacity. Further it is observed that the failure of ash pond, which results in major damage to the environment, is mainly due to ineffective functioning of filters. Such a huge quantity does pose challenging problems, in the form of land usage, health hazards, and environmental dangers. Both in disposal, as well as in utilization, utmost care has to be taken, to safeguard the interest of human life, wild life, and environment.

Every earth fill dam or embankment contains filters and drainage elements for preventing erosion of soil due to the force of seeping water. The purpose of filter in the case of ash dyke is to protect the fly ash against being carried away with seepage and at the same time it should have adequate permeability to take out the seepage water in order to keep the fly ash in a dry condition avoiding liquefaction due to any disturbance. Huge amount of good filter material is required for the construction of filters. Natural river sand is used as the conventional filter material. However, the non-availability of required graded sand in and around construction site and in all seasons possesses problems to the construction of ash dykes. Non-availability of good sand during monsoon also affects the sustained and pre-planned construction of ash dykes in monsoon season. Coarse pond ash and bottom ash which are the waste products of thermal power plant and non-plastic in nature and available abundantly in thermal power plants may replace the conventional sand as a filtering material. This will help in ash utilisation in a small way. However, a detailed investigation on the geotechnical properties particularly, the crushability, permeability, strength properties of these materials is to be studied for efficient functioning of these materials as a drainage system.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 INTRODUCTION

Out of various alternatives for disposal of fly ash and bottom ash, use of ash pond in which ash slurry is discharged is most widely used by thermal power plants. Fly ash and bottom ash from the power plant is mixed with water in a ratio varying from 1 part ash and 4 to 20 parts of water. The slurry is then pumped up to the ash pond which are located within few kilometres distance from the power plant. Further it is observed that the failure of ash pond, which results in major damage to the environment, is mainly due to ineffective functioning of filters. Every earth fill dam or embankment contains filters and drainage elements for preventing erosion of soil due to the force of seeping water. The purpose of filter in the case of ash dyke is to prevent erosion of soil particles from the soil they are protecting and allow drainage of seepage water

Limited work has been reported in the literature on the suitability of either coarse pond ash or bottom ash as a filter material in ash pond dykes. However, many failures of the ash ponds have been reported in past. The main reason for these failures is due to inadequate drainage system. The following sections briefly outline the general layout, planning, designing of ash ponds with special emphasis on requirements and design aspects of inverted filters of ash dykes.

2.2 TYPES OF COAL ASH AND ITS GENERATION

The finer ash particles are carried away by the flue gas to the electrostatic precipitators and are referred as fly ash, whereas the heavier ash particles fall to the bottom of the boiler and are called as bottom ash. A material such as pond ash is a residue collected from ash pond near thermal power plants. Then these two types of ash, mixed together, are transported in the form of slurry and stored in the lagoons, the deposit is called pond ash. Coal ash is a non-plastic and lightweight material having the specific gravity relatively lower than that of the similar graded conventional earth material. Meyer (1976) and Despande (1982) represent that the chemical and physical composition of a pond ash is a function of several variables like coal source, degree of coal pulverization, design of boiler unit, loading and firing condition, handling and storage methods. The coal reserve of India is about 200 billion tonnes and its annual production reaches 250 million tonnes approximately. In India, unlike in most of the developed countries, ash content in the coal used for power generation is about 30 to 40%. The ash generation has increased to about 131 million tonne during 2010-11and shall continue to grow. Table 2.1 shows the recent data of thermal power generation, coal consumption and ash generation in India.

Table.2.1 Thermal power generation, coal consumption and ash generation in India

Year	Thermal power generation (mW)	Coal consumption (mt)	Ash generation (mt)
1995	54,000	200	75
2000	70,000	250	90
2010	98,000	300	131
2020	137,000	350	140

2.3 DISPOSAL PRACTICES

Coal ash is the waste by-product of thermal power plants, which is produced in high quantity and its disposal is a major problem from an environmental point of view and also it requires a lot of disposal areas. Out of the various disposal methods some of the disposal methods are given here. Table 2.2 shows the ash generation & land requirement for disposal of ash.

2.3.1 Wet disposal system- Bottom ash and fly ash, these two types of ashes are mixed thoroughly with large quantities of water and then it is carried out in the form of ash slurry through pipes to dispose off in Ash Ponds. The process of slurry deposition causes segregation of ash mixture. Coarser and heavier particles of ash settle down near the inflow point. Finer light ash particles are carried away and settle near the outflow point. Thus rise to formation of two distinctly different types of materials at inflow and outflow points within the same ash pond. This type of disposal system called wet disposal system is more commonly followed in India and most other parts of the world.

Figure 2.1 Wet Ash Disposal System

2.3.2 Dry Disposal system- another form of disposal of ash is done through dry system in which ash is collected directly through ESPs to the Silos in solid form and then gets dispatched to the vicinity area bricklins or cement manufacturing units. TPPs use to generate ash in this form in small quantity and that too when it is there in demand. If for some TPPs this form is not in demand then they use to make all the ash in bottom ash or wet form and use to dispose it in the ash ponds.

Figure 2.2 Dry Ash Disposal System

2.3.3 High Concentration Slurry Disposal (HCSD) System- this is the latest form of ash disposal system in which ash is collected in bottom ash form only but while disposing it off through ash slurry it requires a huge quantity of water usually in the ratio of 1:20, which can be reduce to say around 1:8 using HCSD system. This is possible because it uses induced draught fan and a mechanism which helps in suction of ash slurry and hence reducing the content of water drastically.

Table 2.2 Ash Generation & Land Requirement for Disposal of Ash

Ash %	Raw Coal Requirement (MTPA)	Ash Generated (MTPA)	Land Requirement (Ha)
41	3.77	1.55	400
36	3.33	1.20	310
34	3.19	1.09	281
32	3.07	0.98	254
30	2.97	0.89	229

2.4 **UTILISATION OF COAL ASH**

Coal ash is a waste product of coal combination in thermal power plants. It possess problem for its safe disposal and causes economic loss to the power plants. Thus, the utilization of pond ash in large scale geotechnical constructions as a replacement to conventional earth material needs special attention.

Pond ash/Fly ash is used for multifarious applications. Some of the application areas are the following:

- In Land fill and dyke rising.
- In Structural fill for reclaiming low areas.
- Manufacture of Portland cement
- Lime – Fly ash Soil Stabilizing in Pavement and Sub-base
- In Soil Conditioning
- Manufacture of Bricks
- Part replacement in mortar and concrete.
- Stowing materials for mines.

Table 2.3 Major Modes of Fly Ash Utilization during the Year 2010-11

Sl. No.	**Mode of Utilization**	**Utilization in annum (mt)**	**Percentage Utilization**
1	Cement	35.47	48.50
2	Reclamation of low lying area	9.31	12.73
3	Roads & Embankments	8.52	11.65
4	Mine filling	6.04	8.26
5	Bricks & Tiles	4.61	6.30
6	Agriculture	1.27	1.74
7	Others	7.91	10.82
	Total	73.13	100

It may be seen from above table that the maximum utilization of fly ash to the extent of 48.50% has been in Cement sector, followed by 12.73% in reclamation of low lying area, 11.65% in roads & embankments etc. The utilization of fly ash in mine filling was 8.26% and in making fly ash based building products like bricks, tiles etc was only 6.3%. These two areas have large potential of ash utilization which needs to be explored for increasing overall ash utilization in the country.

2.5 ASH POND LAYOUT

Following points shall be noted while selecting the location and layout of the ash pond:

1. The area shall be as close as possible to the power plant to reduce the pumping cost.
2. Provisions shall be made for vertical and horizontal expansion of the ash pond depending on estimated life of the power plant
3. To the extent possible, the area shall be away from water bodies such as river, lake, etc. to prevent pollution of the water body due to the seepage of water from ash slurry.

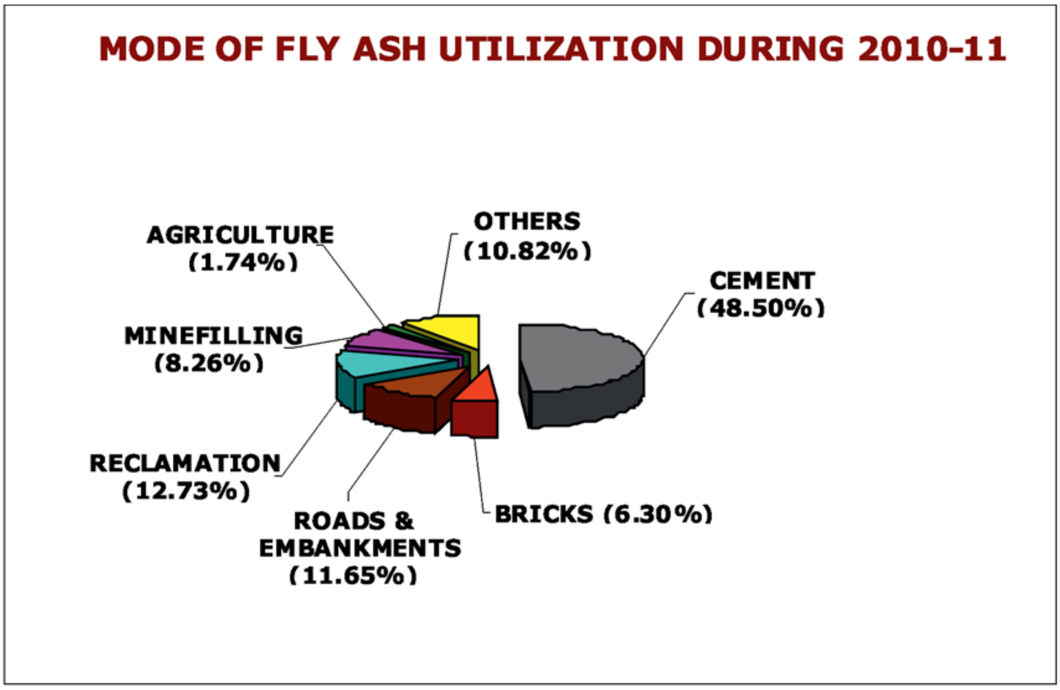

Figure 2.3 shows different ways of fly ash and pond ash being utilized all across the TPPs in India during the year 2010- 2011

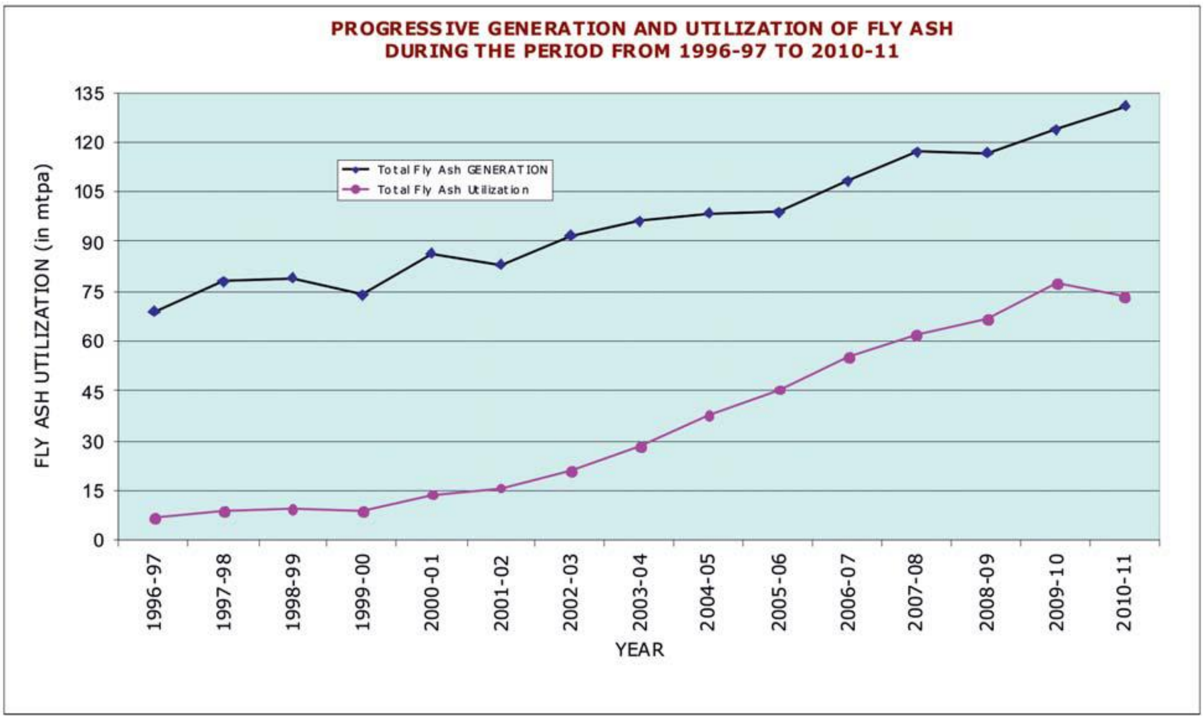

Figure 2.4 Progressive ash generation and its utilization in India

4. In coastal area were ground water is already saline, area with pervious soil is preferable to effectively drain the water through the bottom of the ash pond. Such ash pond can have good drainage, gets drained faster, and have better stability.

5. In the interior areas, even if it is away from water bodies, it is preferable to have a fairly impervious stratum to prevent migration of ash water into the ground water. As per Pollution Control Board norms, an impervious membrane has to be provided to prevent pollution of the ground water.

6. If hilly terrain is within reasonable distance, a suitable valley can be identified for forming the ash pond. In such case, the hill slopes will serve as ash dyke and the length of the dyke to be built will get considerably reduced (eg. Vijaywada and Mettur Power Plants).

In most of the ash ponds, the total area available is divided into two or more compartments so that anyone of the compartment can be in operation while other compartments were ash has already been deposited is allowed to dry and there after the height of the pond is further increased. If the area comprises of a single pond, it is not possible to increase the height while the pond is in operation. Each compartment is required to have certain minimum area to ensure that there is adequate time available for settlement of ash particles while this slurry travels from the discharge point to the outlet point. This distance should be minimum 200m to ensure that only clear water accumulates near the outlet.

2.6 RAISING OF ASH PONDS

The increased embankment height, and the corresponding increase in the ash pond level, imposes greater load on existing embankment and foundation. At the same time, the pore pressure and seepage condition also gets significantly affected. The necessary design features associated with the raising of the embankment are: height of the embankment, crest width, side slope, compacted soil cover to preserve the compaction moisture content, graded filter to arrest piping and having suitable drain characteristic to reduce exit gradient, toe drain to evacuate the seepage water emanating from the foundation and dyke to control the development of excess pore-water pressure, and a trench drain to collect and dispose the emanated water. The suitability of existing filter and other drainage elements must be re evaluated and re-designed at various stages of raising to account for the change in the hydraulic conditions and phreatic line. Furthermore, compacted gravel drains can be installed below the proposed embankment to reduce the possibility of soil liquefaction during earthquake, and to accelerate the consolidation settlement with a target to improve the strength characteristics of the underlying soil. Unlike a water reservoir, the ash pond is generally constructed in stages, each raising having a height of 3-5m. The various methods of stage-wise construction are described herein:

Figure 2.5 Ask Dyke

2.6.1 Upstream Raising

Figure 2.7 depicts the construction sequence adopted in an upstream raising of ash dykes. This is the most preferred method of construction as the quantity of earthwork required is minimal. It provides better environmental pollution control compared to other methods since the constructed embankment being the final face of the ultimate embankment, vegetation and other fugitive dust control and / or leachate control measures can be planned on the permanent basis. Operational requirements such as haul and access roads, culverts, diversion and perimeter ditches may be constructed easily to serve the entire useful life of facility. The starter dam, if properly designed, can be used as a toe filter for the entire embankment.

However, this method has the following disadvantages:

• The entire weight of the new construction for raising the dyke is supported on deposited ash. Unless the ash deposition is done carefully, finer ash particles deposited along the bund may result in significant lowering of the bearing capacity which may be hazardous for new dyke.

• With the increased height of the pond, there is considerable lowering of the plan area of the pond. Beyond certain stage, it becomes uneconomical to raise further height of the dyke.

• The drain provided on the upstream face needs to be suitable connected to the drain of the earlier segment. Improper design with regard to this issue can lead to the rising of the phreatic line and the stability of the slope may be endangered.

• Since the entire segment of the new construction is supported on fly ash, it is important to carry out a liquefaction analysis and if necessary, suitable remediation measures should be adopted.

• The pond needs to remain suspended from operation during the raising of the dyke. This is satisfactorily achieved without the stoppage of the slurry filling if sufficient number of compartments has been provided.

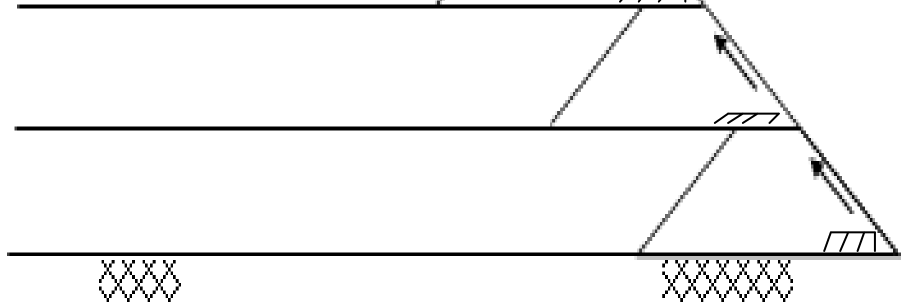

Figure 2.6 Upstream raising of ash dykes

2.6.2 Downstream Raising

Figure 2.8 depicts a typical downstream raising of an ash dyke. This method is most suitable for the construction of new embankments. In this method, the construction is carried out on the downstream side of the starter embankment, so that the crest of the dam is shifted progressively towards downstream and the starter dam forms the upstream toe of the final dam. This method has the following advantages: (i) None of the embankment is built on previously deposited ash, the extensions being placed on the previously constructed earth dam, and hence the issue of lowered baring capacity beneath the raisings does not come into picture. (ii) The placement and compaction control can be exercised as required over the entire fill operation. (iii) The embankment can be raised above its ultimate design height without any serious limitation and design modification, and (iv) In this case it is possible to raise the height of the pond even when the pond is in operation. However, the major disadvantage remains in the non-reduction of construction cost, since the ultimate design height of the dyke is attained in an identical fashion which might have been adopted for constructing the same at a single stretch. Moreover, since in this method, the basal width of the dyke continues to increase in the outward direction, and this might pose a problem if the project site has a restriction on the acquirement of more and more land space.

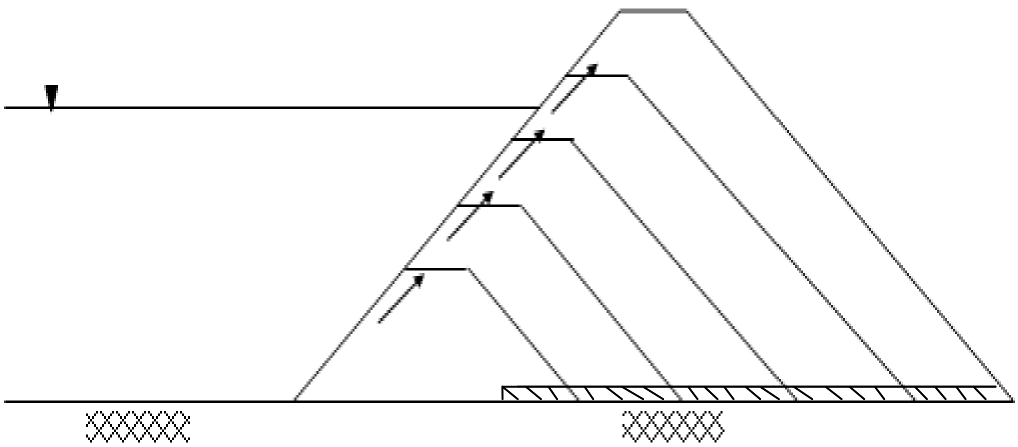

Figure 2.7 Downstream raising of ash dykes

2.6.3 Centre-line Raising

Figure 2.9 depicts a typical centre-line raising of an ash dyke. The center line method is essentially a variation of the downstream method where the crest of the embankment is not shifted in the downward direction but raised in vertically upward above the crest of the starter dam. In this method, after the pond gets filled up to the first stage, material is placed for raising height of the dyke on either side of centre line of the dyke such that the center line of the dyke remains at the same location. This requires part of the raw material to be placed on the deposited ash and part of the material on the downstream face of the existing dyke. The earth work required in this case is less compared to the construction while downstream method. However, as the material is required to be deposited on the settled fly ash, it is not possible to carry out the construction when the pond is in operation. This method can be adopted only if the total area of ash pond is divided into compartments. The center line method leads to many design, construction, environmental and operational problems and as such it is not generally used. At present, often combinations of both upstream and downstream methods are employed to optimize the disposal scheme.

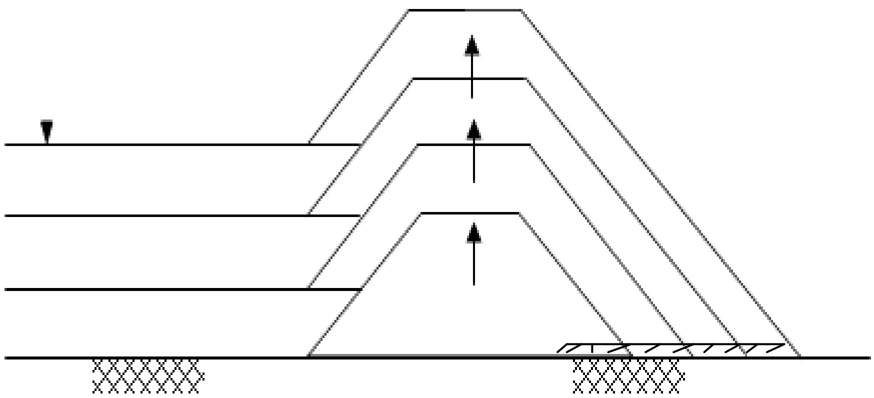

Figure 2.8 Centre-line raising of ash dykes

2.6.4 Offset Raising

This method can be used when the existing embankment is extremely weak to support the loading caused by raised embankment. Figure 2.10 depicts a typical example of offset raising. This method has the same issues as the down-stream raising, but are to be more seriously dealt, since apart from the starter dyke being weak, the offset has to rest on the slurry. Hence, the attainment of stability in terms of slope and bearing failure is under serious question. As such, this method is only used to tackle extremely unprecedented situations. As can be comprehended from the above discussions, various raising techniques pose different types of challenges in the construction and to maintain the integrity and safety of ash dykes. The threat to safety is mainly dealt in terms of the slope failures of the dykes and bearing failure of the bases. The following section reports few case studies where different methods had been adopted or have been proposed to tackle such stability issues for various ash dykes.

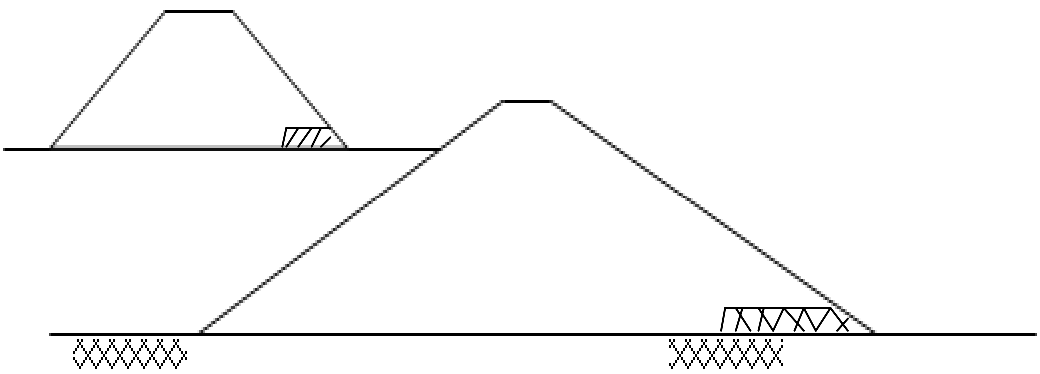

Figure 2.9 Offset raising of ash dykes

2.7 INVERTED FILTER AND ITS DESIGN

The use of protective filters prevents erosion and reduces uplift pressure. A protective filter consists of one or more layers of coarse-grained free draining material placed over a less pervious soil called the base. A filter would prevent the migration of finer particles but without inhibiting the flow of seepage water, so there is hardly any less of head. This ensures that within the filter itself, seepage forces are reduces.

If these criteria can't be met by one filter layer or the layer thickness is insufficient, several layers of filter, each coarser than the one below it and each layer satisfying the specified filter criteria with respect to the lower layer, are to be used. Such a multi layered filter is called a graded filter or an inverted filter.

If voids in the filter layer are much larger than the finest grains of the protected material (base), these grains are likely to be washed into the voids of the filter material and would ultimately obstruct the free flow. On the other hand, if the voids in the filter are to small, seepage forces are likely to develop to unacceptable levels. Both these situations have to be avoided. To achieve this, the filter material must have grain sizes that satisfy certain requirements. Terzaghi (1922) defined certain criteria for protective filters. These have been subsequently extended by the Corps of Engineers at Vicksburg, USA. They are based primarily on the grain size distributions of the filter material and the protected material.

The filter specifications are given below:

1. D_{15}(filter)/D_{85}(protective material)<5
2. i. D_{15}(filter)/D_{15}(protective material)>4

   ii. D_{15}(filter)/D_{15}(protective material)<20
3. D_{50}(filter)/D_{50}(protective material)<25

D_{15}, D_{50}, and D_{58} refer to the particle sizes from the grain size distribution curves.

The first specification ensures that no significant invasion of particles from the protected soil to the filter shall take place. This governs the upper limit to the grain sizes of filter material. The first part of the second criteria will ensure that sufficient head is lost in flow through the filters without a build-up of seepage pressure. This specifies the lower limit for the size of filter material. The third criterion and the second part of the second criterion are additional guides for the selection of filter material.

To achieve these functions the ideal filter will have following characters

- Not segregate during processing, handling, placing, spreading or compaction
- Not change in gradation during processing, handling, placing, spreading or compaction, or degrade with time.
- Not have any apparent or real cohesion, or ability to cement as a result of chemical, physical or biological action so the filter will not allow a crack in the soil it is protecting to persist through the filter
- Be internal stable, that is the fines particles in the filter should not erode from the filter under seepage flows
- Have sufficient permeability to discharge the seepage flows without excessive build-up of head
- Have the ability to control and seal the erosion which may have initiated by a concentrated leak , backward erosion , or suffusion (internal stability) in the base soil

2.8 CHARACTERIZATION OF PONDASH

Ghosh et al. (2010) presents the laboratory test results of a Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and PG (0.5, and 1.0), to study the suitability of stabilized pond ash for road base and sub-base construction. Standard and modified Proctor compaction tests have been conducted to reveal the compaction characteristics of the stabilized pond ash. Bearing ratio tests have been conducted on specimens, compacted at maximum dry density and optimum moisture content obtained from standard Proctor compaction tests, cured for 7, 28, and 45 days. Both un-soaked and soaked bearing ratio tests have been conducted. This paper highlights the influence of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash. The empirical model has been developed to estimate the bearing ratio for the stabilized mixes through multiple regression analysis. Linear empirical relationship has been presented herein to estimate soaked bearing ratio from un-soaked bearing ratio of stabilized pond ash. The experimental results indicate that pond ash-lime-PG mixes have potential for applications as road base and sub base materials.

Bera et al. (2007) presented the study on compaction characteristics of pond ash. Three different types of pond ash have been used in this study. The effects of different compaction controlling parameters, viz. compaction energy, moisture content, layer thickness, mould area, tank size, and specific gravity on dry density of pond ash are highlighted herein. The maximum dry density and optimum moisture content of pond ash vary within the range of 8.40–12.25 kN/m3 and 29–46%, respectively. In the present investigation, the degree of saturation at optimum moisture content of pond ash has been found to vary within the range of 63–89%. An empirical model has been developed to estimate dry density of pond ash, using multiple regression analyses, in terms of compaction energy, moisture content, and specific gravity. Linear empirical models have also been developed to estimate maximum dry density and optimum moisture content in the field at any compaction energy. These empirical models may be helpful for the practicing engineers in the field for planning the field compaction control and for preliminary estimation of maximum dry density and optimum moisture content of pond ash.

Bera et al. (2007) implemented on the effective utilization of pond ash, as foundation medium. A series of laboratory model tests have been carried out using square, rectangular and strip footings on pond ash. The effects of dry density, degree of saturation of pond ash, size and shape of footing on ultimate bearing capacity of shallow foundations are presented in this paper. Local shear failure of a square footing on pond ash at 37% moisture content (optimum moisture content) is observed up to the values of dry density 11.20 kN/m3 and general shear failure takes place at the values of dry density 11.48 kN/m3 and 11.70 kN/m3. Effects of degree of saturation on ultimate bearing capacity were studied. Experimental results show that degree of saturation significantly affects the ultimate bearing capacity of strip footing. The effect of footing length to width ratio (L/B), on increase in ultimate bearing capacity of pond ash, is insignificant for $L/B \geq 10$ in case of rectangular footings. The effects of size of footing on ultimate bearing capacity for all shapes of footings viz., square, rectangular and strip footings are highlighted.

Oscar Victor M. Antonio, Mark Albert H. Zarco (2007) determined the engineering properties of Calaca, Batangas bottom ash. These engineering properties used to find and assessed the possible ways of utilizing and maximizing the potential of such byproduct in a manner that is both environmentally friendly as well as economically viable.

Das and Yudhbir (2005) gave the experimental studies with regard to some common engineering properties e.g., grain size, specific gravity, compaction characteristics, and unconfined compression strength of both low and high calcium fly ashes, to evaluate their suitability as embankment materials and reclamation fills. In addition, morphology, chemistry, and mineralogy of fly ashes were studied using scanning electron microscope, electron dispersive x-ray analyzer, x-ray diffractometer, and infrared absorption spectroscopy. The distinct difference between self-hardening and pozzolanic reactivity also emphasized.

N. S. Pandian (2004) studies carried out on review of characterization of the fly ash with reference to geotechnical applications. He summarized that fly ash with some modifications/additives, (if required) can be effectively utilized in geotechnical applications.

Kumar and Stewart (2003) conventionally found that physical properties of coal ashes are assumed to be similar to natural sands, as it has appearance of natural sands and their particles are in the range of fine sands.

Pandey et al. (2002) attempted to devise the ways for the use of this mixed ash for manufacturing mixed ash clay bricks successfully. The bricks thus made are superior in structural and aesthetic qualities and portents huge saving in the manufacturing costs with better consumer response.

Kumar et al. (1999) gives the results of laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibres. The test results reveal that the inclusion of fibres in soils increases the peak compressive strength, CBR value, peak friction angle, and ductility of the specimens. It is concluded that the optimum fibre content for both silty sand and pond ash is approximately 0.3 to 0.4% of the dry unit weight.

Leonards (1972) reported that untreated pulverised coal ash with no cementing quantities was used successfully as a material for structural fill. Although, the ash was inherently variable, it could be compacted satisfactorily, if the moisture content was maintained below the optimum obtained from standard laboratory tests and if the percentage of fines (passing the No.200 sieve) was below 60%.

2.9 STRENGTH PROPERTIES OF POND ASH

Abdulhameed Umar Abubakar, Khairul Salleh Baharudin (2012) reviewed of the strength characteristics of concrete and mortar as influenced by coal bottom ash (CBA) as partial replacement of fine aggregate is presented based on the available information in the published literatures. They also presented diverse physical and chemical properties of CBA from different power plants in Malaysia. They discussed the influence of different types, amounts and sources of CBA on the strength and bulk density of concrete. They highlighted the setting time, workability and consistency as well as the advantages and disadvantages of using CBA in construction materials. An effective utilization of CBA in construction materials will significantly reduce the accumulation of the by-products in landfills and thus reduce environmental pollution.

Raju Sarkar, S.M. Abbas and J.T. Shahu (2012) conducted a test on pond ashes mixed with another waste - marble dust which is generated as a by-product during cutting of marble, investigated the geotechnical properties like the strength, deformability, volume stability (shrinking and swelling), permeability, erodibility, durability etc. This paper presented the details of the pond ashes, the experiments carried out to characterize them when mixed with marble dust.

Jakka et al. (2010) studied carried on the strength and other geotechnical characteristics of pond ash samples, collected from inflow and outflow points of two ash ponds in India, are presented. Strength characteristics were investigated using consolidated drained (CD) and undrained (CU) triaxial tests with pore water pressure measurements, conducted on loose and compacted specimens of pond ash samples under different confining pressures. Ash samples from inflow point exhibited behaviour similar to sandy soils in many respects. They exhibited higher strengths than reference material (Yamuna sand), though their specific gravity and compacted maximum dry densities are significantly lower than sands. Ash samples from outflow point exhibited significant differences in their properties and values, compared to samples from inflow point. Shear strength of the ash samples from outflow point are observed to be low, particularly in loose state where static liquefaction is observed.

R. S. Jakka, G. V. Ramana, M. Datta (2010) gave a detailed experimental study carried on the strength and other geotechnical characteristics of pond ash samples, collected from inflow and outflow points of two ash ponds. Strength characteristics were investigated using consolidated drained (CD) and un-drained (CU) triaxial tests with pore water pressure measurements, conducted on loose and compacted specimens of pond ash samples under different confining pressures.

Bera et al. (2009) have studied the shear strength response of reinforced pond ash, a series of unconsolidated undrained (UU) triaxial test has been conducted on both unreinforced and reinforced pond ash. In the present investigation the effects of confining pressure ($\sigma 3$), number of geotextile layers (N), and types of geotextiles on shear strength response of pond ash are studied. The results demonstrate that normal stress at failure ($\sigma 1f$) increases with increase in confining pressure. The rate of increase of normal stress at failure ($\sigma 1f$) is maximum for three layers of reinforcement, while the corresponding percentage increase in r1f is around (103%), when the number of geotextile layers increases from two layers to three layers of reinforcement. With increase in confining pressure the increment in normal stress at failure, Δr increases and attains a peak value at a certain confining pressure (threshold value) after that Δr becomes more or less constant. The threshold value of confining pressure depends on N, dry unit weight (γd) of pond ash, type of geotextile, and also type of pond ash.

Bumjoo Kim, Monica Prezzi and Rodrigo Salgado (2005) conducted the tests like compaction, permeability, strength, stiffness, and compressibility on class F fly ash and bottom ash were collected from two utility power plants in Indiana and solid residue by products produced by coal-burning. Three mixtures of fly and bottom ash with different mixture ratios i.e., 50, 75, and 100% fly ash content by weight were prepared for testing. They found that direct use of these materials in construction projects consuming large volumes of materials, such as highway embankment construction, not only provides a promising solution to the disposal problem, but also an economic alternative to the use of traditional materials.

Huang (1990) studied the shear strength characteristics of bottom ash using direct shear tests were conducted on compacted Indiana bottom ash to different densities. It was that reported variation of friction angles over wide range (35–55 degree) depending on the density.

2.10 PERMEABILITY AND DRAINAGE PROPERTIES OF POND ASH

Kumar, J. and Naresh, D.N (2012) conducted a case study on the use of bottom ash as filter in lieu of sand as internal drainage for exiting the hydraulic gradient.

Pedro J. Amaya, John T. Massey-Norton, and Timothy D. Stark (2009) presented the cause of fly ash-laden seepage from the right abutment of an earthen dam. The investigation shows that the sediment-laden seepage occurred through permeable/jointed bedrock in the right abutment that was exposed by a landslide prior to construction of the dam. When the level of the impounded fly ash reached the level of the prior landslide, the fly ash-laden seepage migrated through the jointed bedrock of the abutment and exited on the downstream right abutment.

Pedro J. Amaya, Andrew J Amaya (2007) described the engineering properties of bottom ashes that led to their selection in the design of dams that form Horse Ford Creek fly ash reservoir in Kentucky, Muskingum River Plant Upper Reservoir in Ohio, and Tanners Creek fly ash pond in Indiana.

Gandhi (2005) described the design and maintenance of ash pond for fly ash disposal. Various method of raising the dyke was explained in their work including the advantage and disadvantage. It was suggested that the ash dyke should be superved regularly and necessary remedial measures should be taken. This is based on the observation and experience at different pond sites.

G.A. Leonardo, A.B. Huang, and Jose Ramos (1991) conducted tests on the filtration characteristics of the chimney drains and on the erodibility of the upstream clay blanket at Corner Run Dam. Conclusions were drawn regarding the potential of compacted clay to erode internally and on the validity of current filter criteria to prevent piping from occurring. The beneficial effects of fly ash in the reservoir to control piping of clay blanket were also evaluated.

S. R. Gandhi, Gima V. Mathew (1996) conducted tests on amount of penetration, amount of bypassing and amount of clogging of fly ash through different size sand filter.

Jayapalan (1981) reviewed failures of 16 tailings dams and ash dykes which were caused due to the instability of dams constructed using the upstream method due to excessive pore pressures and absence of adequate internal drainage. This made them susceptible to liquefaction and flow failures.

Digioa (1972) says that with drainage, the ash can be effectively and economically utilized as a fill material to construct stable embankment for land reclamation on which structure can be safely founded.

Dobry and Alvarez (1967) studied seismic failures of some tailings dams in Chile and found that the reason being inadequate drainage.

Terzaghi (1920) established two rational grain size criteria, $d_{15f}/d_{85b} < 5$, and $d_{15f}/d_{15b} > 5$ for earthen dams. The first criterion prevents largest base material grains from being carried into pores of the filter materials. Washout of smaller grains can then be prevented by means of internal formation of filter. Second criterion ensures water to easily drain.

2.10 SCOPE OF THE PRESENT STUDY

Filter media and internal drains are the important part of ash dyke for stability and effective functioning of ash dyke. Non-availability of good sand as filter material during monsoon and just after monsoon creates a problem in construction of ash dyke. Coarse pond ash and bottom ash which are the waste products and non-plastic in nature and available abundantly may replace the conventional sand as a filtering material.

SCOPE:

- To characterize the coarse pond ash and bottom ash
- To study the geotechnical properties of coarse pond ash and bottom ash to find out their suitability as filter material such as permeability, strength, and crushing properties.
- To find out the filter criteria and check whether these materials are suitable as a filter media after being subjected to different loading intensities.

CHAPTER-3

EXPERIMENTAL WORK AND METHODOLOGY

EXPERIMENTAL WORK AND METHODOLOGY

3.1 INTRODUCTION

The coal ash can be utilized in bulk only in geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc. Thus, through literature review it is observed that several attempts have already been made by researchers to effective utilisation coal ash as civil engineering material but 100 % utilisation of coal ash is not achieved till date. Utilisation of bottom ash and coarse pond ash as filter material of ash dyke is one of the recent research. Limited researchers focus on evaluation of the geotechnical properties of coal ash and their utilisation in filter media. However, no field application is made due to lack of sufficient literature and confidence. This work undertakes to find out the geotechnical properties of coal ash subjected to different loading intensity and its filter criteria. During construction of new ash dyke or raising of existing dykes the dyke material is likely to be subjected to both dynamic and static compaction stresses. So the filter materials will crush during construction. In this present work physical property, index properties, and geotechnical properties of coarse pond ash, bottom ash, and sand have been found out when samples were subjected to both dynamic and static compaction and also model test has been done to find out the filtering capabilities of these materials. Details of material used, sample preparation and testing procedure adopted have been outlined in this chapter.

3.2 MATERIAL USED

Coal ashes like bottom ash and coarse pond ash samples used in this study were collected from hopper and ash pond of NTPC, Kaniha, Odisha respectively. Coarse sand was collected from Brahmini River. Fly ash was collected from RSP, Rourkela. These samples were dried at the temperature of 105-110^0 C. The physical properties were determined and are presented in Table-3.1.

Table 3.1 Physical properties of coarse pond, bottom ash and sand

Physical parameter	**Pond Ash**	**Bottom Ash**	**Fly Ash**	**Sand**
Colour	Light grey	Grey colour with unburned coal	Grey colour	Grey colour
Shape	Rounded/ sub rounded	Rounded/ sub rounded	Rounded	Angular or sub angular
Mean diameter	0.3 mm	0.28 mm	0.05 mm	0.7
Uniformity coefficient	3.33	3.52	8.57	2
Coefficient of curvature	1.2	1.028	0.024	1.125
Specific gravity, G	2.18	2.12	2.08	2.65
Plasticity index, I_p	Non-plastic	Non-plastic	Non-plastic	Non-plastic
Loss on ignition	0.347	4.0265	0.23	0

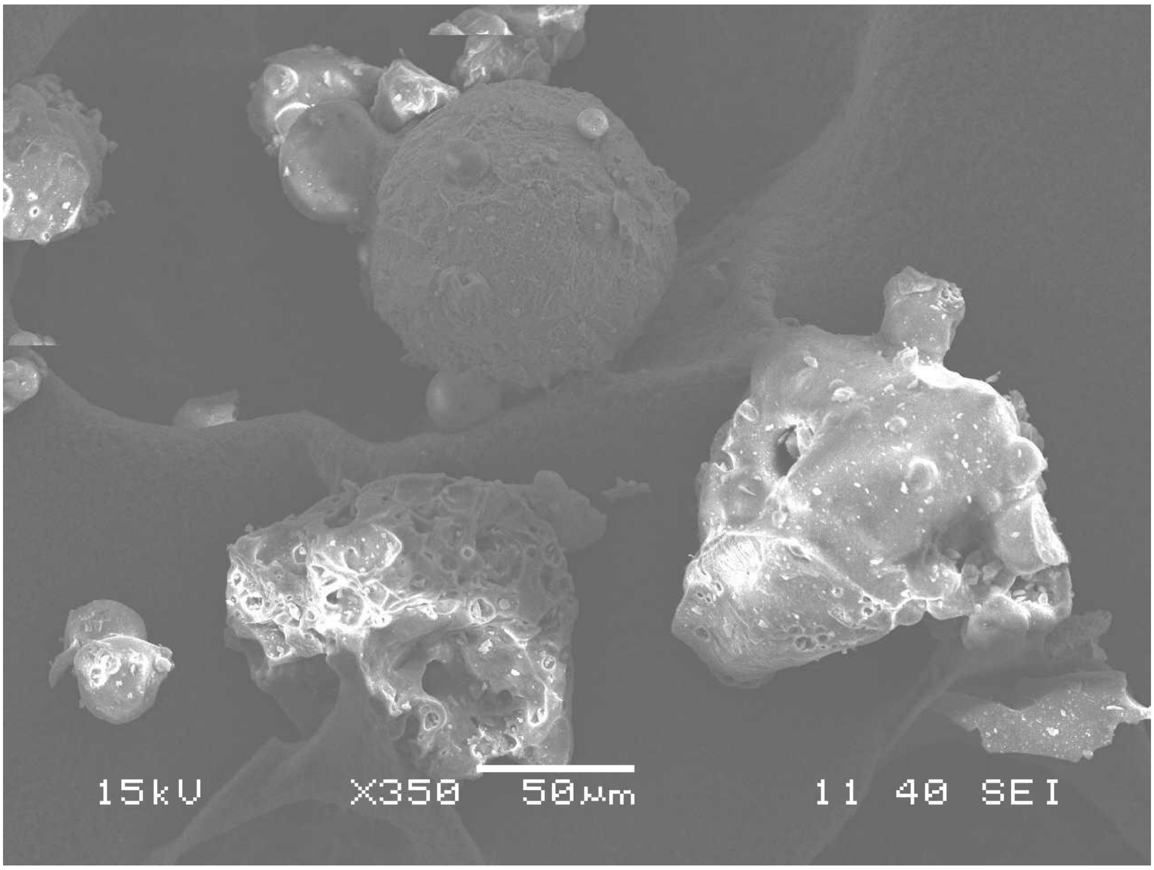

Fig.3.1 Scanning Electron Micrograph (SEM) of Pond Ash

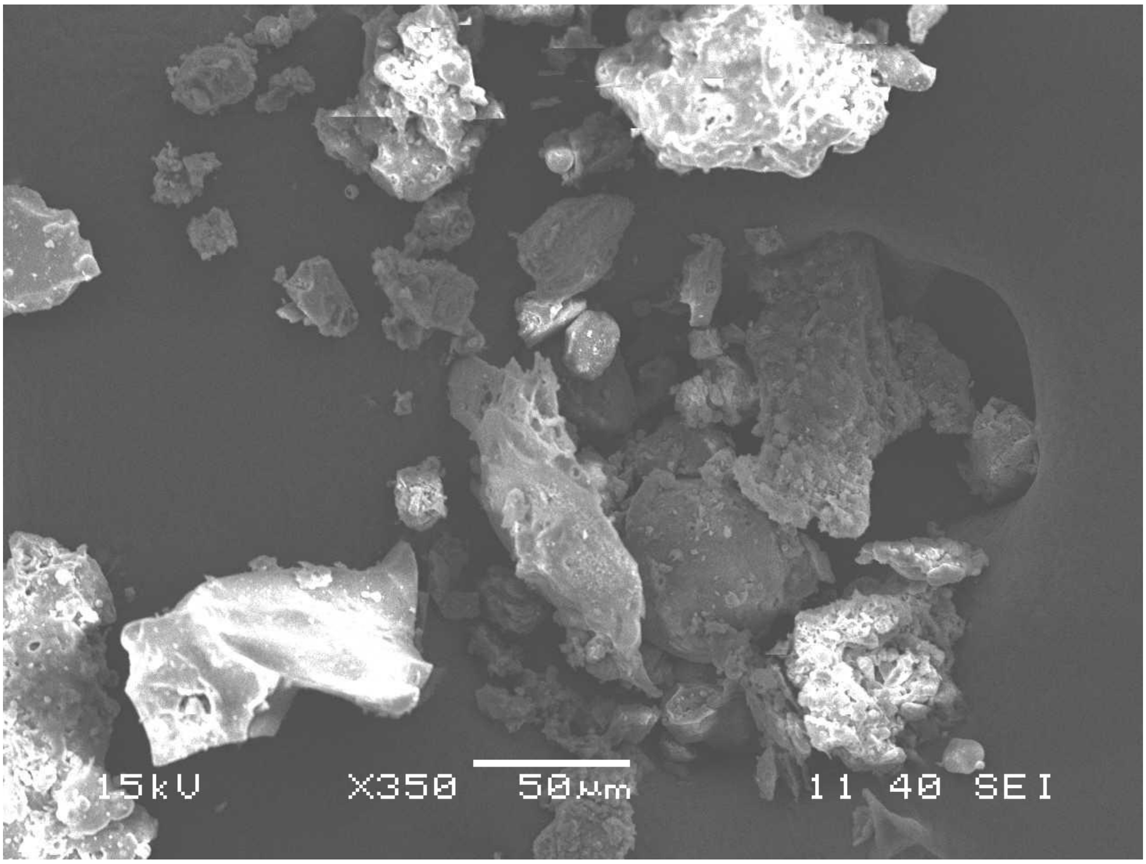

Fig.3.2 Scanning Electron Micrograph (SEM) of Bottom Ash

3.3 TEST PROGRAMME AND METHODOLOGY

3.3.1 Determination of index properties

Pond ash sample was collected from discharge point of ash pond and bottom ash from the boiler of the NTPC, Kaniha. Sand was collected from Brahamini River. These samples were thoroughly mixed individually to bring homogeneity and were dried at oven temperature of 105 to 110^0C. The index properties like grain size distribution curve, specific gravity, plasticity index of both the samples were determined as per the Indian Standard Code of practice IS-2720 part (IV), IS-2720 part (III) and IS-2720 part (VI) respectively. The test results are presented in Table 1.

3.3.2 Determination of physical properties

3.3.2.1 Sample preparation

Coal ashes like pond ash, bottom ash samples and sand were subjected to dynamic compactions in a Proctor mould at dry state either in using standard Proctor rammer of 2.6 kg or modified Proctor rammer of 4.5 kg. The number of blows and layers are so adjusted that the resulting compactive effort (E) on the sample are either149, 595, 1070, 2674 or 4278 kJ/m^3. Similarly all these samples of pond ash, bottom ash, and sand were subjected to different static pressures of $400kN/m^2$, $160000kN/m^2$, $6400kN/m^2$, $25600kN/m^2$ in compressive testing machine. In this way samples for pond ash, bottom ash, and sand, subjected to different dynamic compacting efforts and static compaction pressure were prepared. These samples were kept in air tight containers for future use. For all these samples, individually grain size distribution, maximum, and minimum dry density, permeability and shear parameters were determined.

3.3.2.2 Grain size distribution

Grain size distributions for all samples (pond ash, bottom ash, and sand) were conducted as per IS: 2720 part (IV) for coarse fractions and hydrometer analysis were conducted for finer particles. The grain size distribution curves of pond ash, bottom ash, and sand subjected to both dynamic and static compaction are presented in Fig. 3.1 to Fig.6. Coefficient of uniformity (C_u), coefficient of curvature (C_c) and mean diameter (D_{50}) of the samples for pond ash, bottom ash, and sand are presented in Table 3.2. Filter criteria were found out from this grain size distribution curve of pond ash and bottom ash.

3.3.2.3 Maximum and minimum dry density

Minimum and maximum dry density of pond ash, bottom ash, and sand were determined as per IS-2720 part (14) for samples that have been subjected to different dynamic compactive energies and static pressures. Minimum dry density was determined by filling the standard mould in sand raining method to their loosest state. Maximum dry density was determined with respect to their densest state using vibrating table and putting a surcharged weight over it, as per provisions of IS-2720 part (14). The results are presented in Table 3.4 and Table 3.

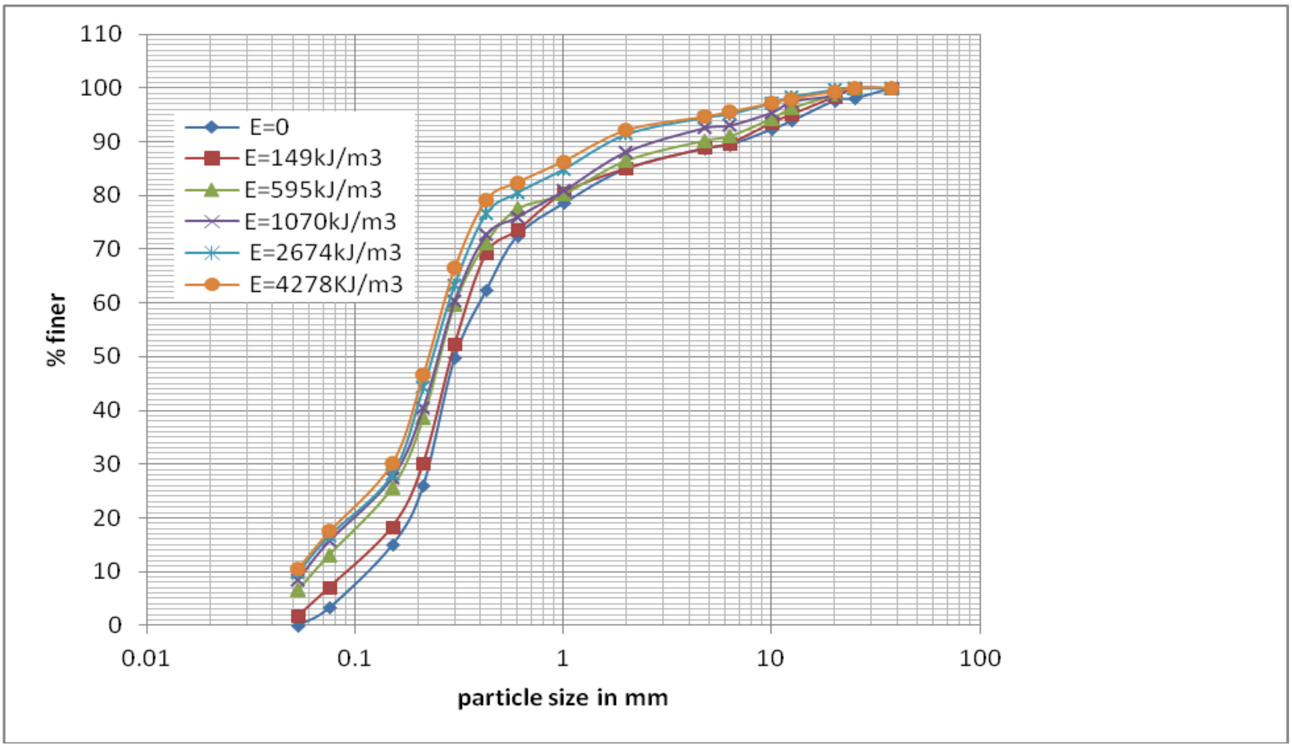

Fig 3.3 Grain size distribution curve of pond ash subjected to dynamic compaction

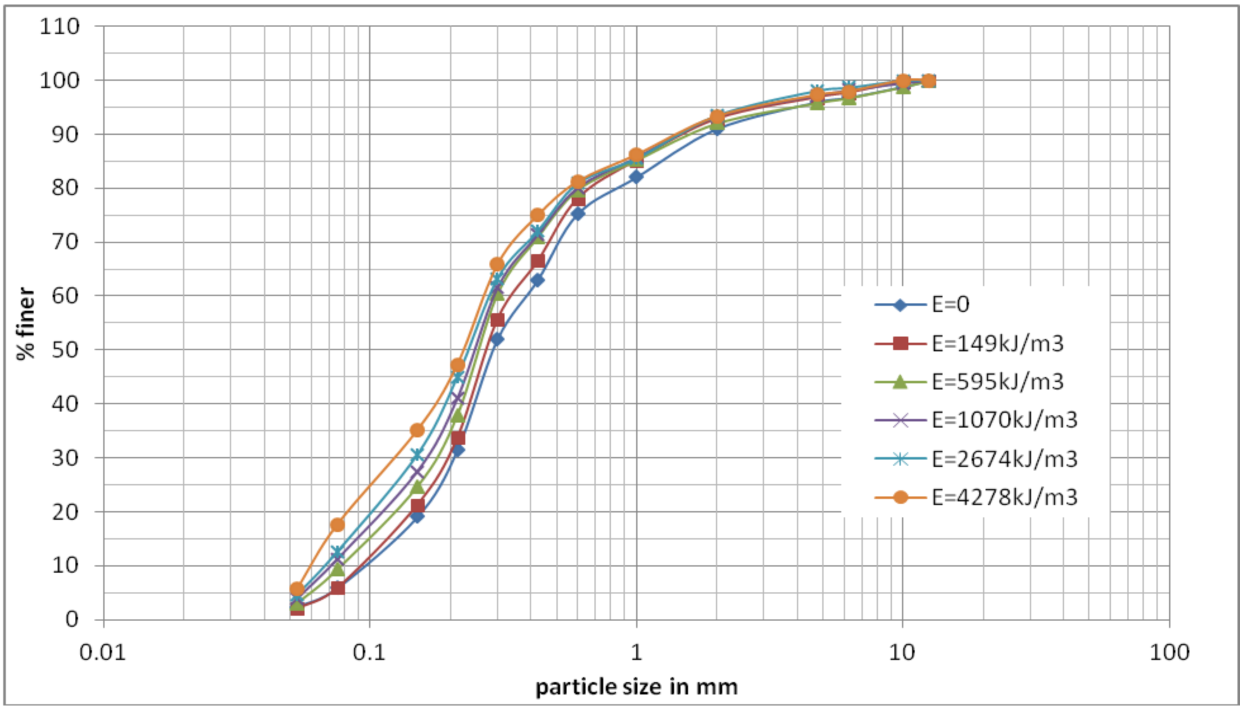

Fig. 3.4 Grain size distribution curve of bottom ash subjected to dynamic compaction

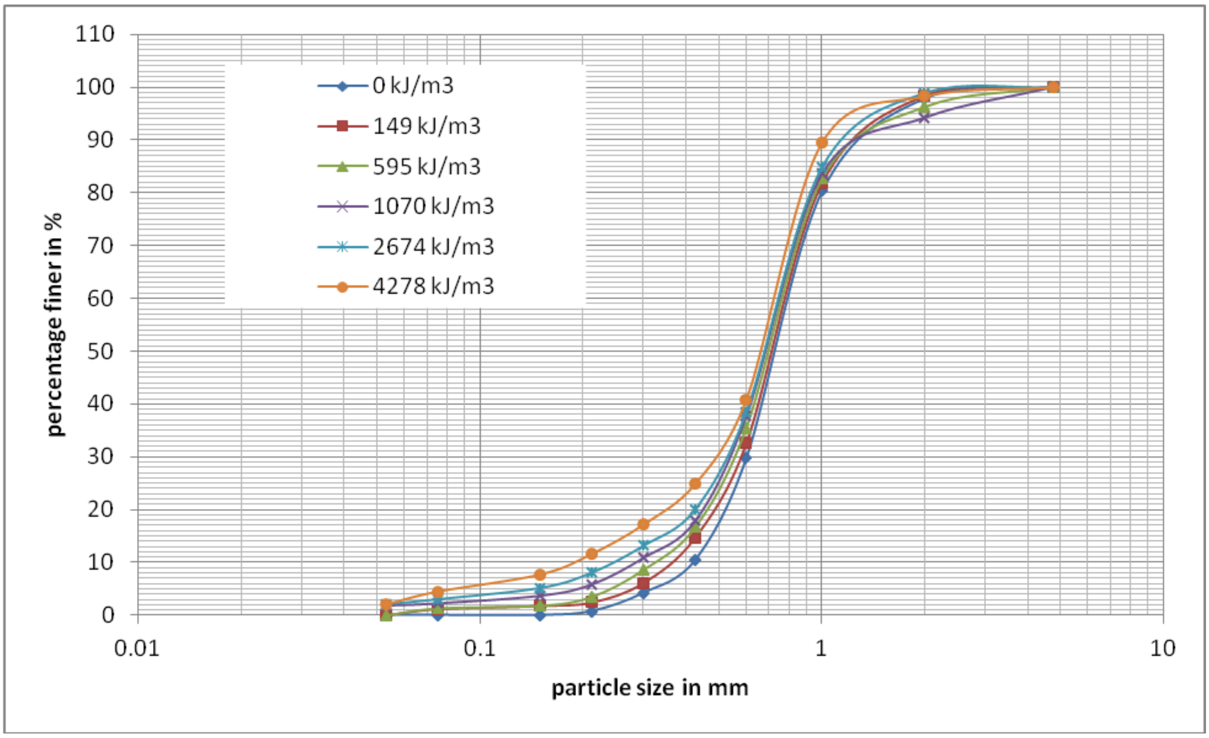

Fig 3.5 Grain size distribution curve of sand subjected to dynamic compaction

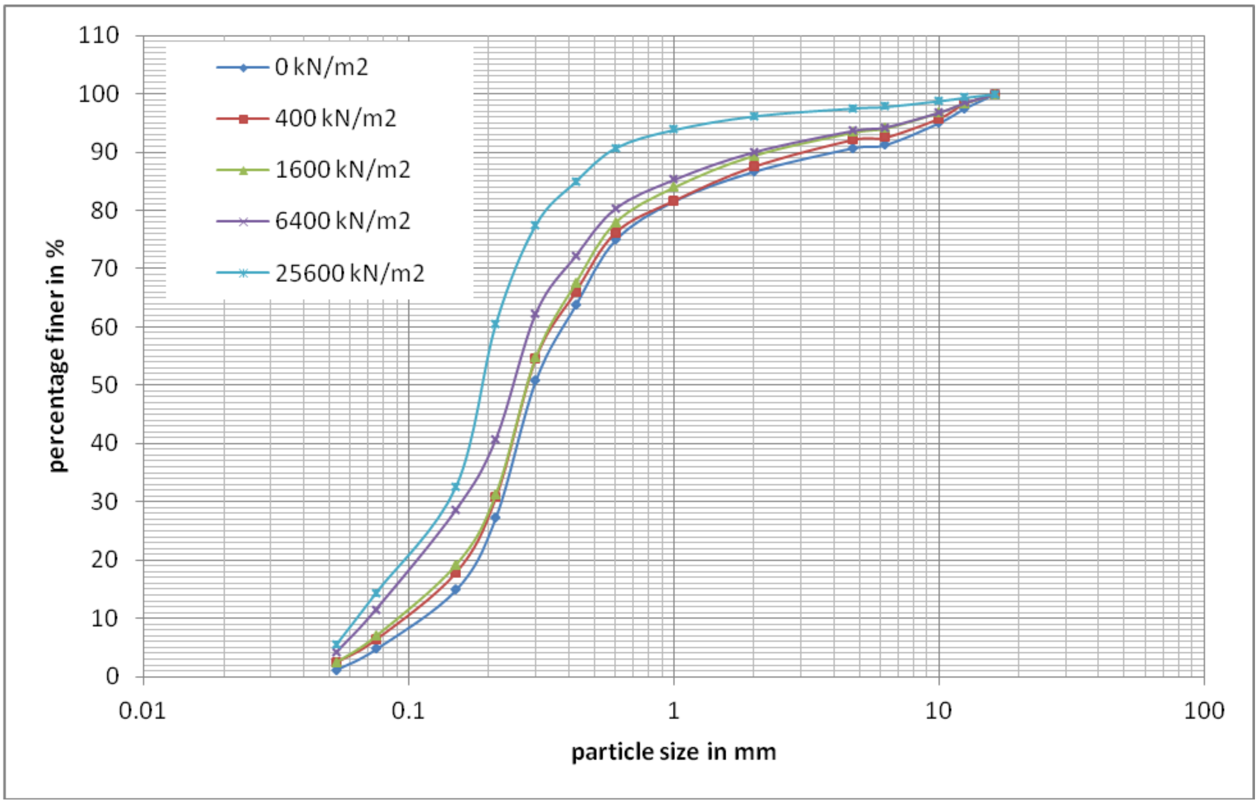

Fig 3.6 Grain size distribution curve of pond ash subjected to static compaction

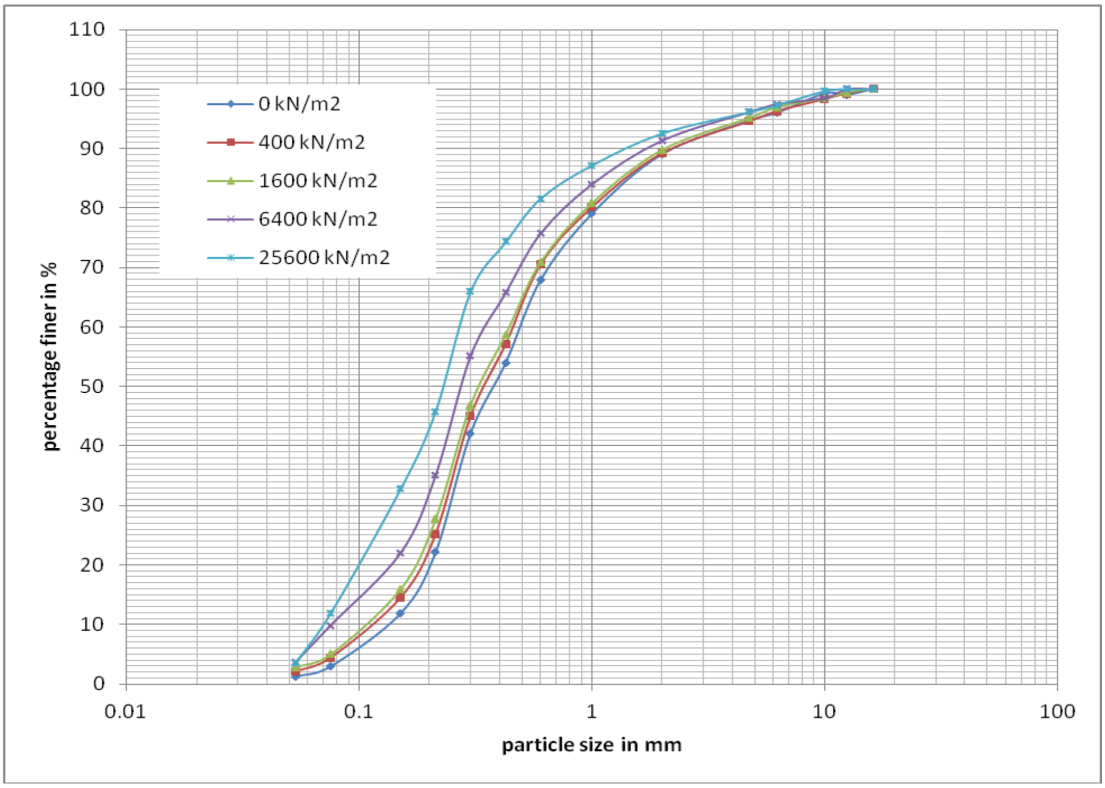

Fig 3.7 Grain size distribution curve of bottom ash subjected to static compaction

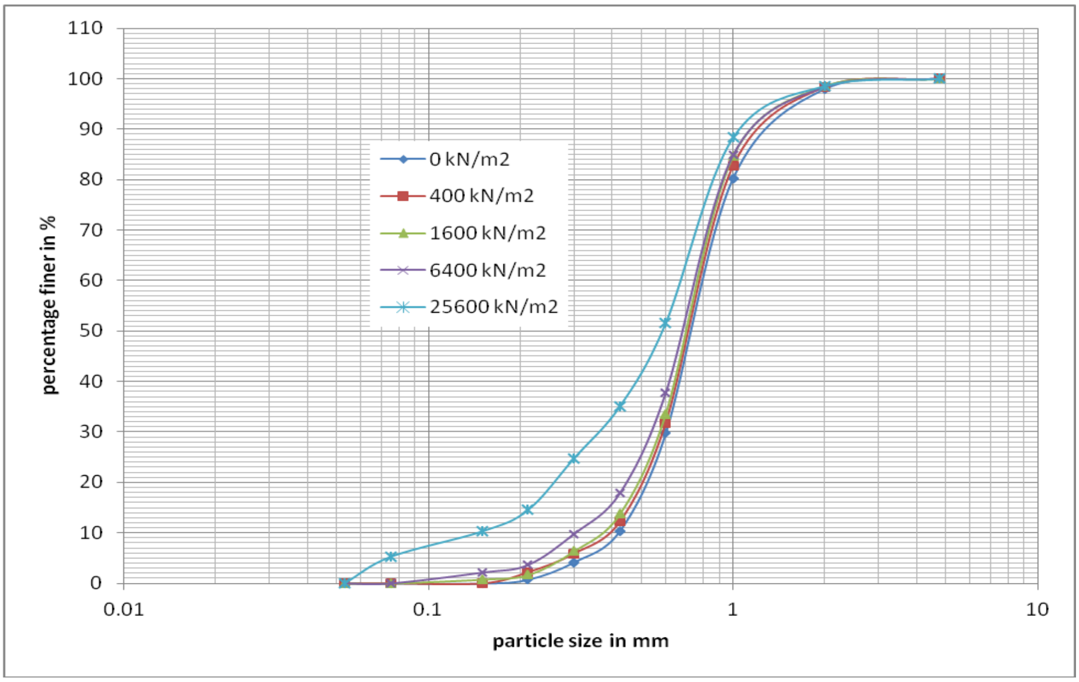

Fig 3.8 Grain size distribution curve of sand subjected to static compaction

Table3.2. Coefficient of uniformity, coefficient of curvature and mean diameter of the samples subjected to dynamic compaction

Compaction energy in kJ/m^3	Pond Ash			Bottom ash			Sand		
	D_{50} in mm	C_u	C_c	D_{50} in mm	C_u	C_c	D_{50} in mm	C_u	C_c
0	0.31	3.33	1.2	0.29	3.25	0.83	0.73	1.95	1.172
149	0.29	3.88	1.4	0.267	3.69	1.154	0.72	2.05	1.174
595	0.26	4.91	1.77	0.26	3.79	1.219	0.70	2.37	1.335
1070	0.258	5.08	1.8	0.25	4.20	1.279	0.70	2.55	1.461
2674	0.24	5.185	1.85	0.24	4.37	1.366	0.69	2.88	1.680
4278	0.23	5.192	1.9	0.23	5.79	1.392	0.68	3.74	1.853

Table3.3 Coefficient of uniformity, coefficient of curvature and mean diameter of the samples subjected to static compaction

Static stress in kJ/m^2	Pond Ash			Bottom ash			Sand		
	D_{50} in mm	C_u	C_c	D_{50} in mm	C_u	C_c	D_{50} in mm	C_u	C_c
0	0.31	3.33	1.2	0.29	3.25	0.83	0.73	1.95	1.172
400	0.29	3.67	1.25	0.28	3.75	0.97	0.71	1.975	1.130
1600	0.29	3.88	1.46	0.26	4.2	1.05	0.7	2.00	1.143
6400	0.25	4.14	1.52	0.23	4.66	1.52	0.68	2.50	1.296
25600	0.19	4.38	1.66	0.22	4.75	1.58	0.6	4.53	1.342

Table 3.4 Minimum and maximum dry densities of samples, subjected to different compacting energies

Compaction Energy kJ/m^3	Pond ash		Bottom ash		Sand	
	minimum dry density in gm/cc	maximum dry density in gm/cc	minimum dry density in gm/cc	maximum dry density in gm/cc	minimum dry density in gm/cc	maximum dry density in gm/cc
0	0.8025	1.009	0.8001	0.972	1.416	1.746
149	0.858	1.081	0.901	1.087	1.420	1.748
595	0.8795	1.11	0.938	1.138	1.445	1.752
1070	0.9245	1.161	0.946	1.144	1.474	1.801
2674	1.0135	1.223	0.994	1.203	1.508	1.856
4278	1.0369	1.254	1.036	1.246	1.524	1.876

Table 3.5 Minimum and maximum dry densities of samples, subjected to different static stress

Static stress in kJ/m^2	Pond ash		Bottom ash		Sand	
	minimum density in gm/cc	maximum dry density in gm/cc	minimum density in gm/cc	maximum dry density in gm/cc	minimum density in gm/cc	maximum dry density in gm/cc
0	0.8025	1.009	0.8001	0.972	1.416	1.746
400	0.829	1.032	0.806	0.999	1.418	1.748
1600	0.858	1.056	0.839	1.029	1.422	1.755
6400	0.998	1.142	0.948	1.132	1.452	1.783
25600	1.125	1.223	1.071	1.122	1.537	1.916

3.3.2.4 Coefficient of permeability

Pond ash, bottom ash and sand samples that were subjected to compaction energy of 149, 595, 1070, 2674 and 4278 kJ/m^3 and static stresses of 400 kN/m^2 , 1600 kN/m^2 , 6400 kN/m^2 , 25600 kN/m^2 were used in this test program. Samples were prepared corrosponding to their minimum and maximum dry density in a permeability mould in dry state. Constant head permeability test was run as per IS: 2720 (part 36)1987 and the coefficient of permeability were determined. Values of coefficient of permeability of these samples at their minimum and maximum void ratios are presented in Table. 3.6 and Table. 3.7 respectively.

Table 3.6 Coefficient of permeability of pond ash, bottom ash and sand samples subjected to dynamic compaction

Compaction Energy kJ/m^3	Coefficient of permeability in 10^{-3} cm/sec					
	Pond ash		Bottom ash		Sand	
	At minimum dry density	At maximum dry density	At minimum dry density	At maximum dry density	At minimum dry density in	At maximum dry density in
0	11.54	8.40	8.547	5.38	15.205	13.548
149	10.06	7.193	7.264	4.49	15.018	13.164
595	9.070	5.147	5.611	2.656	14.909	12.568
1070	8.204	4.162	4.669	1.415	13.001	11.064
2674	6.327	2.246	2.28	0.791	12.986	9.678
4278	4.256	1.354	1.123	0.551	10.356	7.379

3.3.2.5 Crushing coefficient:

The samples of pond ash, bottom ash, and sand were compressed with static stresses of 400kN/m^2, 1600 kN/m^2, 6400 kN/m^2, and 25600kN/m^2 in compression testing machine. For all the samples subjected to static stress grain size distribution curves were determined. Then Crushing Coefficient, Cc is defined as the ratio of the percentage of post stressed sample finer than D_{10} of the original sample divided by the percentage of original sample finer than D_{10} of the original sample. Cc values of three samples given in Table 3.8

$$Cc = (\text{\% of post stressed sample finer than } D_{10} \text{ of original sample}) / 10$$

Table 3.7 Coefficient of permeability of pond ash, bottom ash and sand samples subjected to different static stresses

Static stress kJ/m^2	Coefficient of permeability in 10^{-3} cm/sec					
	Pond ash		Bottom ash		Sand	
	At minimum dry density	At maximum dry density	At minimum dry density	At maximum dry density	At minimum dry density	At maximum dry density
0	11.54	8.40	8.547	5.388	15.205	13.548
400	10.379	8.197	7.956	4.911	15.006	13.315
1600	9.406	6.339	7.326	3.672	14.689	12.432
6400	4.977	3.333	5.649	2.393	13.299	10.555
25600	1.413	0.687	0.663	0.365	10.524	4.458

Table 3.8 Values of crushing coefficient of pond ash, bottom ash, and sand

Static stress in kN/m^2	Pond Ash	Bottom Ash	Sand
400	1.1	1.2	1
1600	1.2	1.3	1.1
6400	1.7	1.9	1.8
25600	2.4	2.5	3.4

3.3.2.6 Determination of Shear Parameters

The shear parameters of both the sample compacted to their corresponding dry density with compactive effort varying as 149, 595, 1070, 2674 and 4278 kJ/m^3 and static stress of 400 kN/m^2 , 1600 kN/m^2 , 6400 kN/m^2 , 25600 kN/m^2 were determined as per IS: 2720 (Part 13) 1986[13]. Test specimens were prepared corresponding to their maximum and minimum dry densities. These specimens were of size 60mm×60mm×25mm deep and sheared at a rate of 1.25 mm/minute. The shear strength parameters of the compacted specimens were determined from normal stress versus shear stress plots and it is given in Table 3.9 and Table 3.10

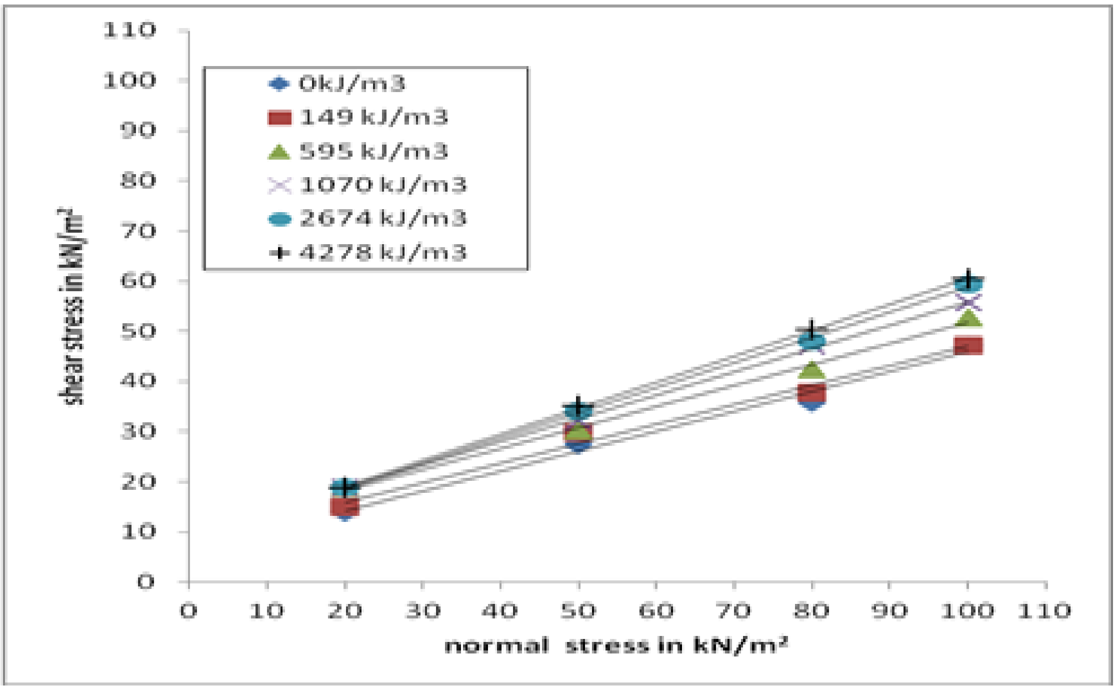

Fig.3.9 Shear stress verses normal stress graph of pond ash at minimum dry density condition subjected to dynamic compaction

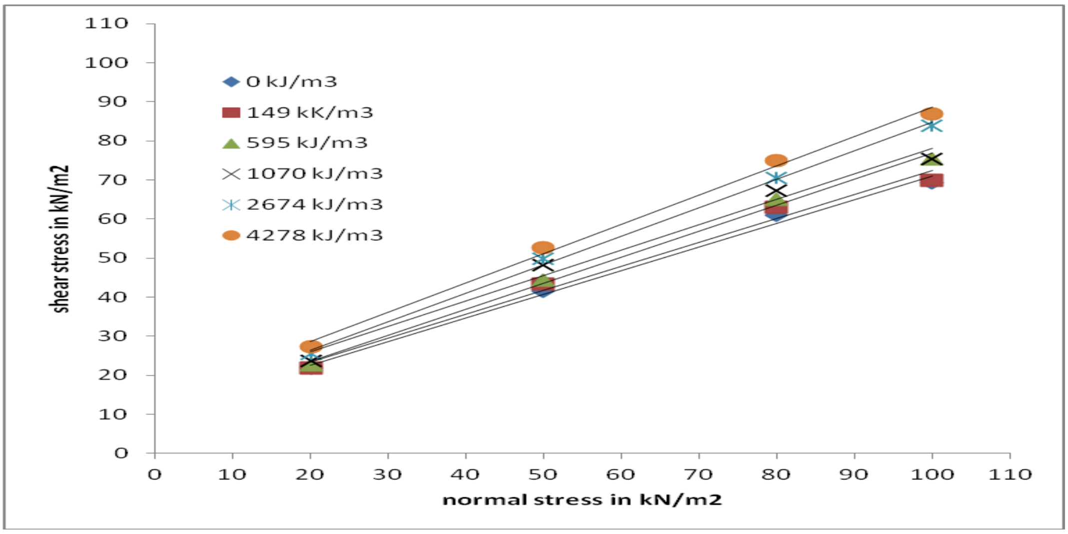

Fig. 3.10 Shear stress verses normal stress graph of pond ash at maximum dry density condition subjected to dynamic compaction

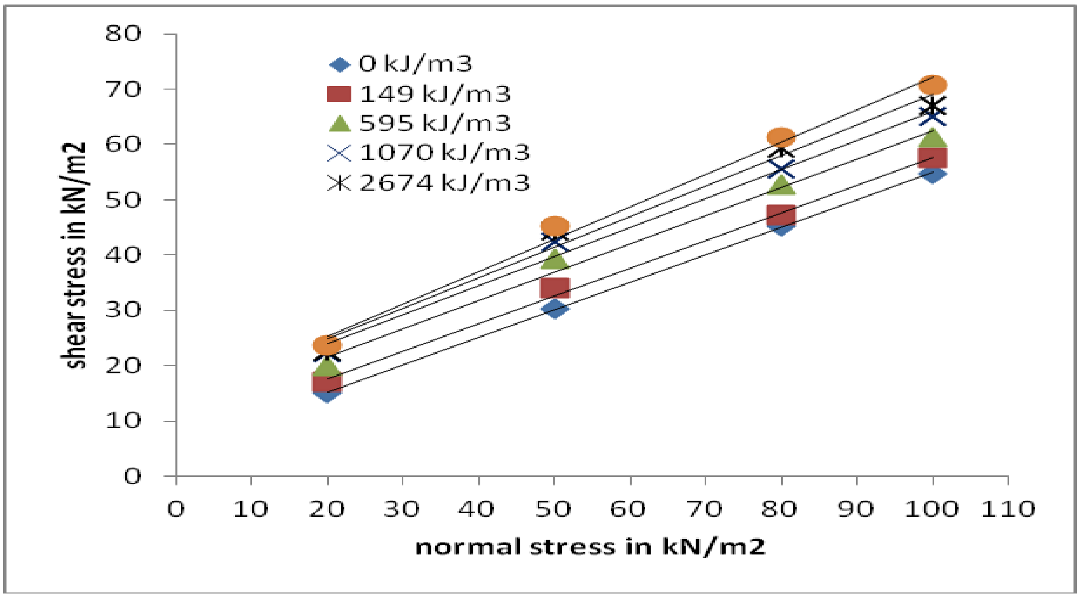

Fig. 3.11 Shear stress verses normal stress graph of bottom ash at minimum dry density condition subjected to dynamic compaction

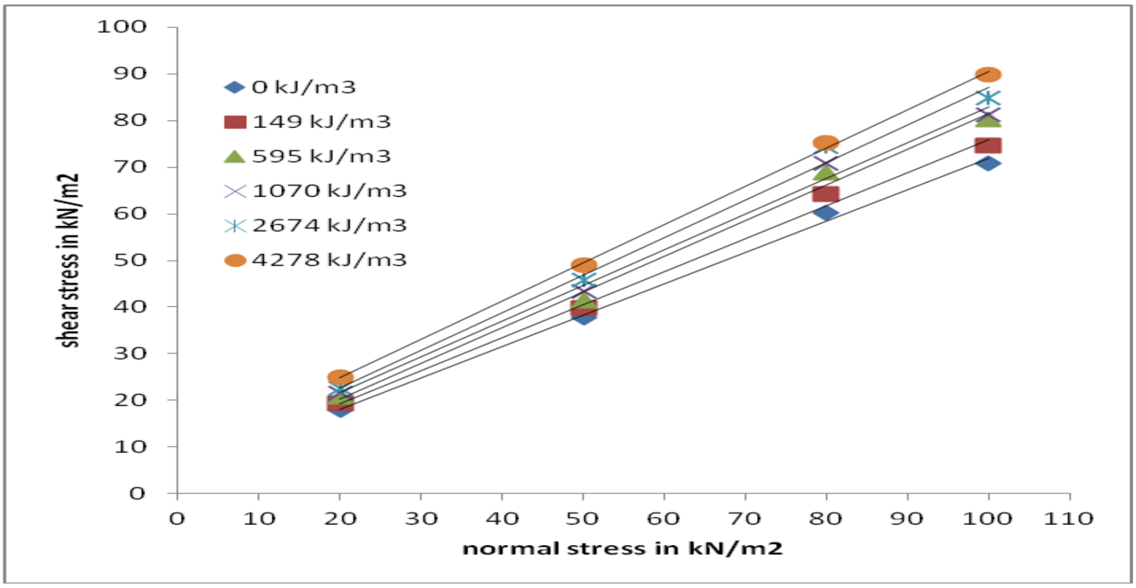

Fig. 3.12 Shear stress verses normal stress graph of bottom ash at maximum dry density condition subjected to dynamic compaction

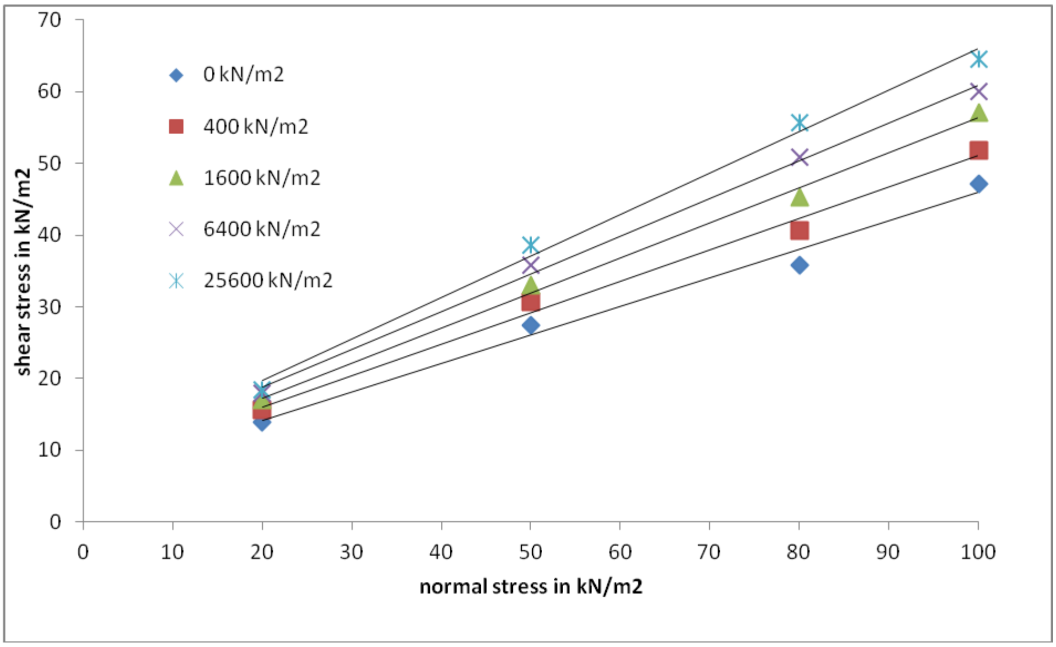

Fig. 3.13 Shear stress verses normal stress graph of pond ash at minimum dry density condition subjected to static stresses

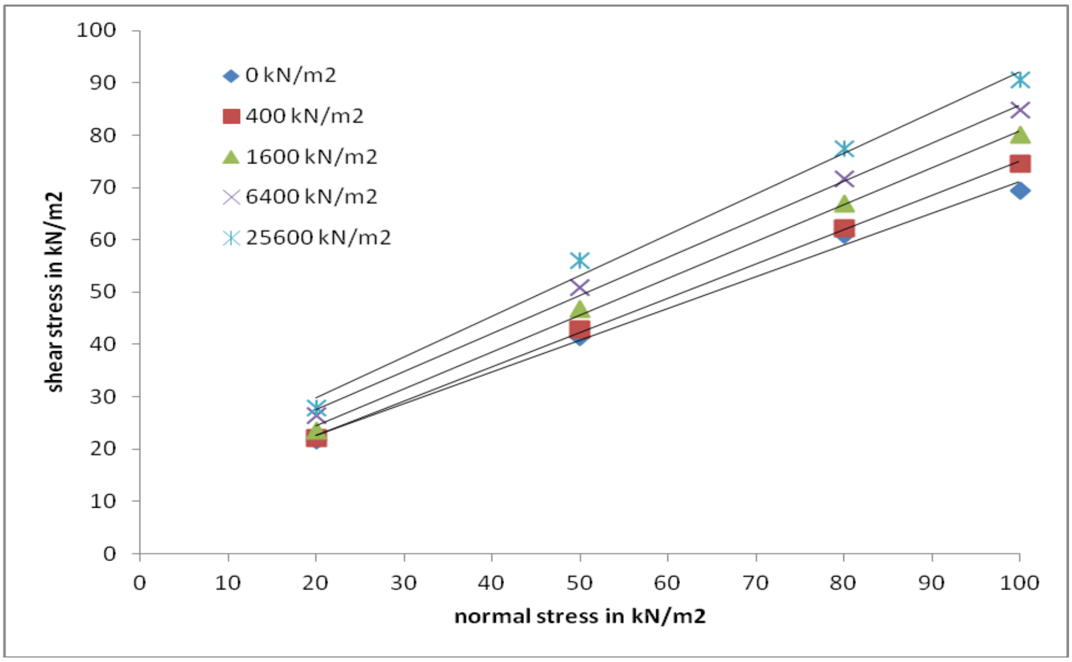

Fig. 3.14 Shear stress verses normal stress graph of pond ash at maximum dry density condition subjected to static stresses

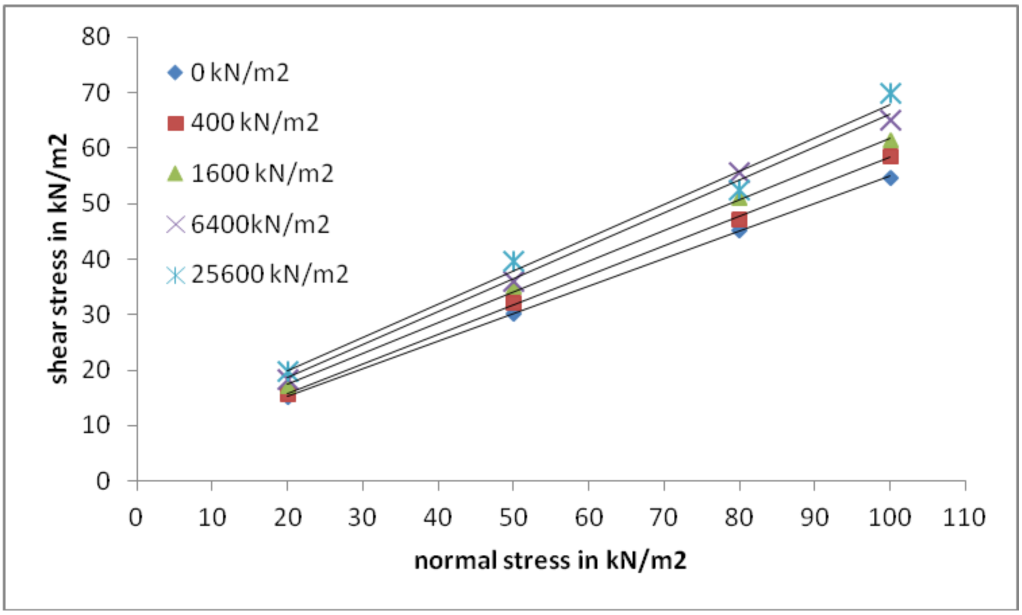

Fig.3.15 Shear stress verses normal stress graph of bottom ash at minimum dry density condition subjected to static stresses

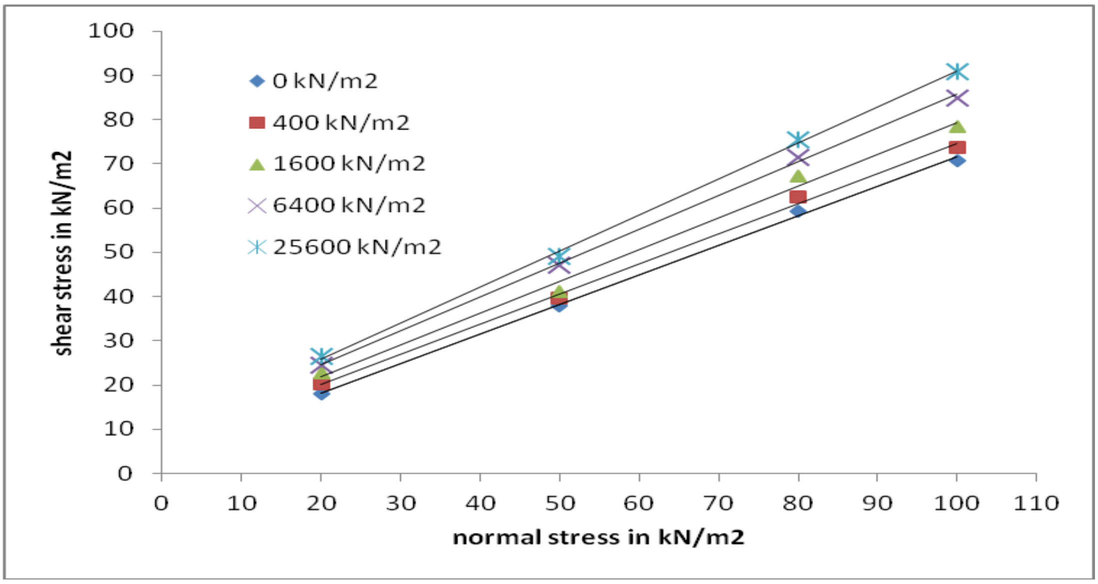

Fig.3.16 Shear stress verses normal stress graph of bottom ash at maximum dry density condition subjected to static stresses

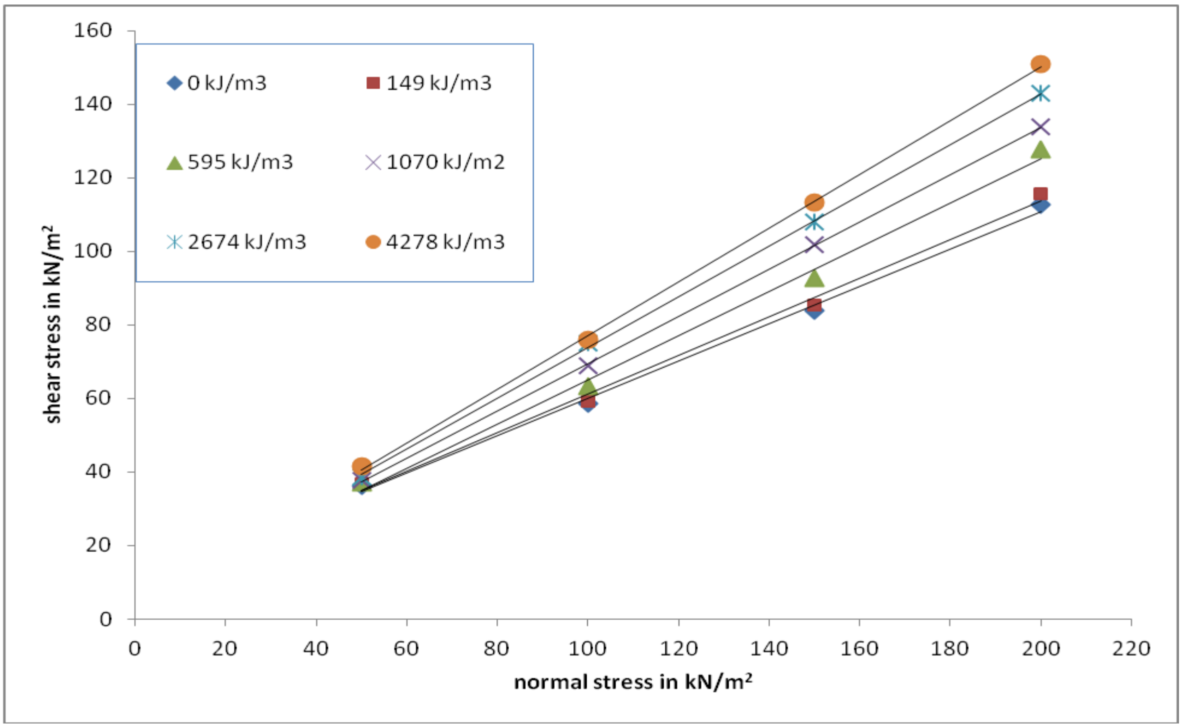

Fig. 3.17 Shear stress verses normal stress graph of sand at minimum dry density condition subjected to dynamic compaction

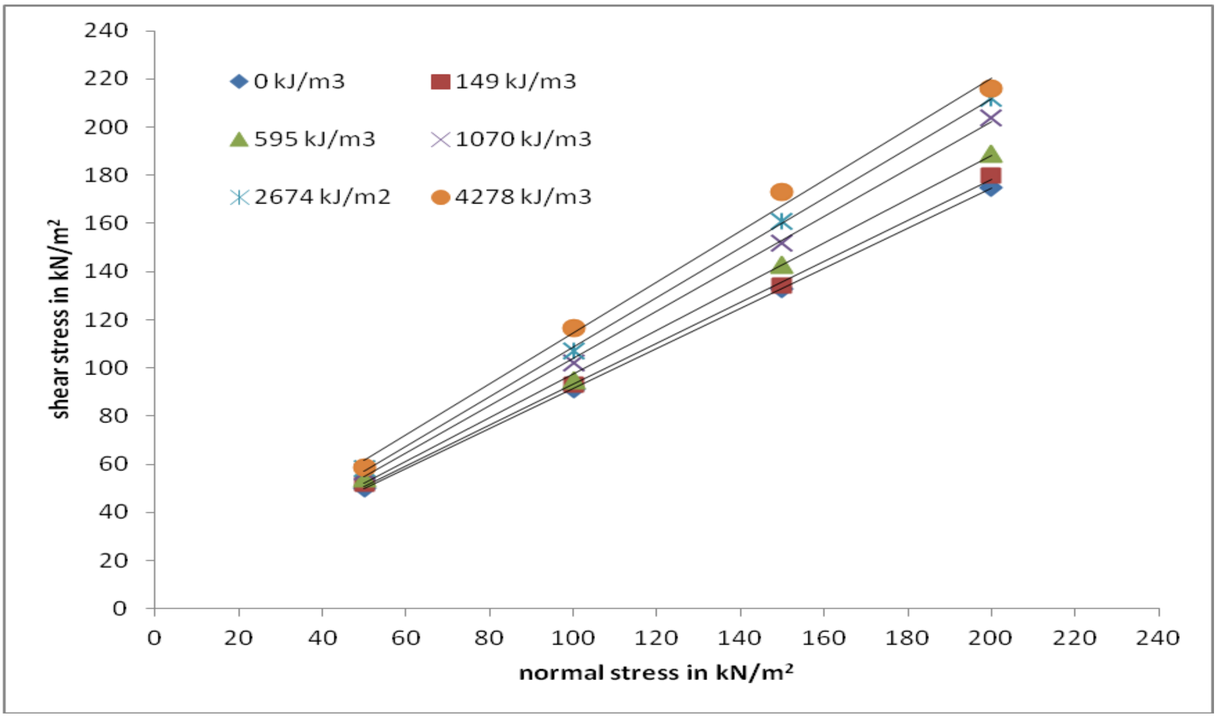

Fig. 3.18 Shear stress verses normal stress graph of sand at maximum dry density condition subjected to dynamic compaction

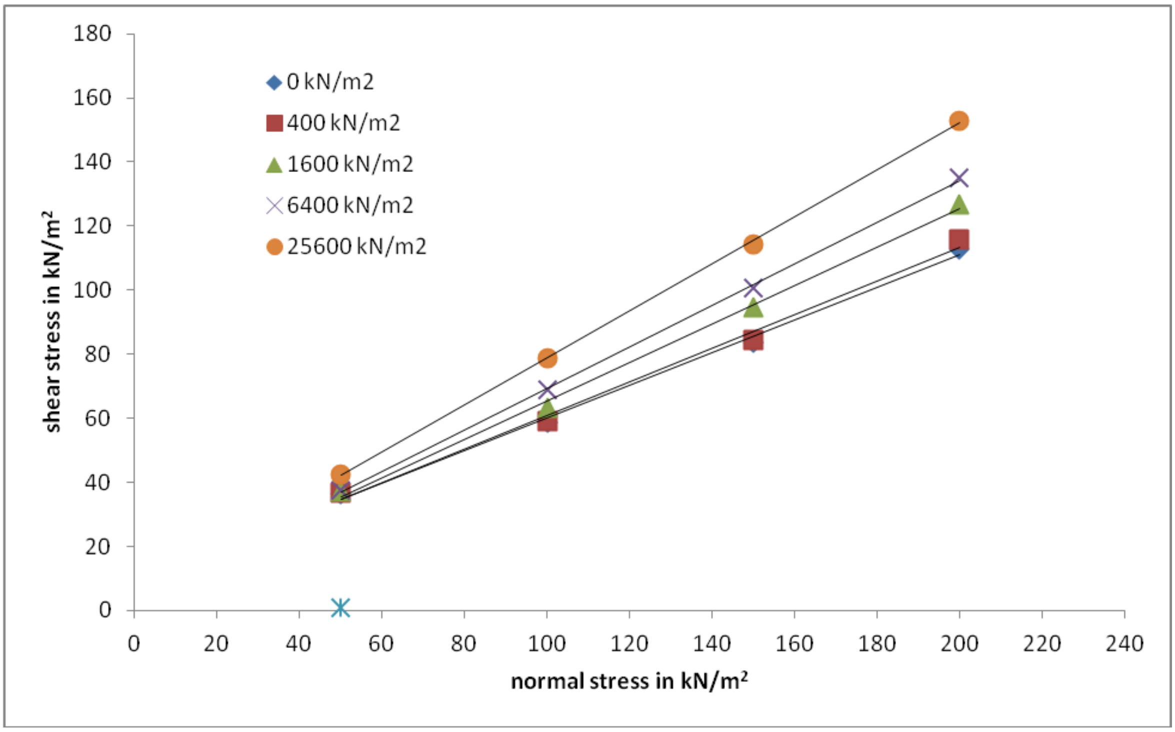

Fig. 3.19 Shear stress verses normal stress graph of sand at minimum dry density condition subjected to static stresses

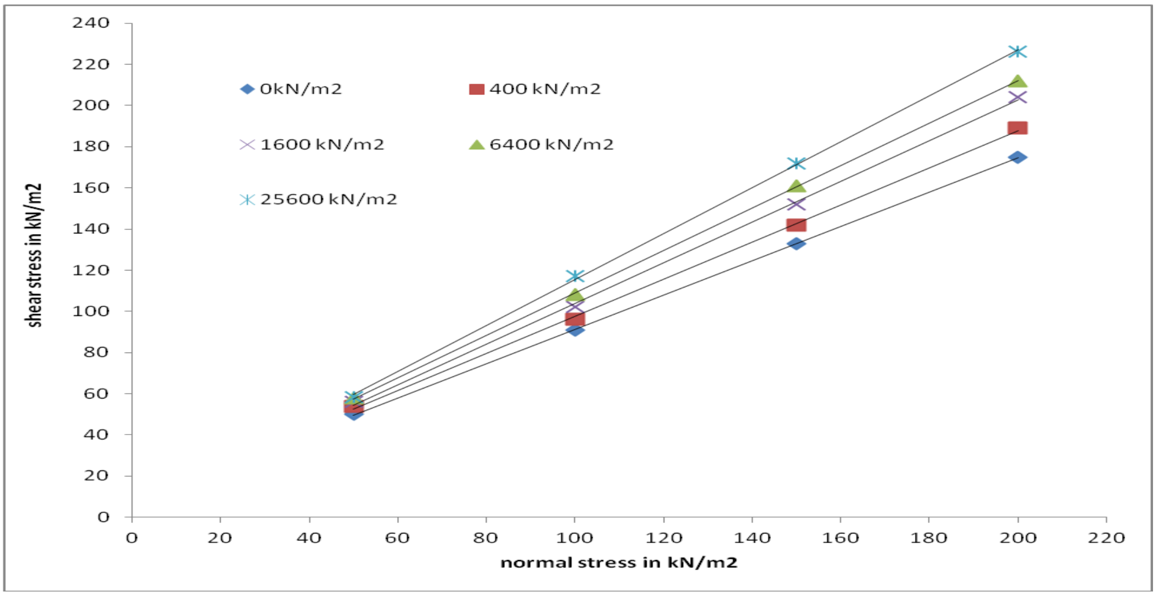

Fig.3.20 Shear stress verses normal stress graph of sand at maximum dry density condition subjected to static stresses

Table 3.9 Shear parameters of pond ash, bottom ash and sand samples subjected to dynamic compaction

Compaction energy in kJ/m^3	Pond ash				Bottom ash				Sand			
	Minimum dry density condition		Maximum dry density condition		Minimum dry density condition		Maximum density condition		Minimum dry density condition		Maximum dry density condition	
	C in kN/m^2	Φ in (^{0})	C in kN/m^2	Φ in (^{0})	C in kN/m^2	Φ in (^{0})	C in kN/m^2	Φ in (^{0})	C in kN/m^2	Φ in (^{0})	C in kN/m^2	Φ in (^{0})
0	4.5	22.42	7	30.43	6	25.04	6.5	33.02	5	26.86	6	40.03
149	6	23.03	8.2	31.48	6.5	25.98	8	34.01	5	27.47	6	40.91
595	8	23.63	9.5	32.00	7	26.56	8.5	37.32	5.5	30.39	6	41.77
1070	9	24.82	10	33.02	9	27.69	10	38.22	6	32.07	6.5	44.23

2674	9.2	26.56	10.82	35.47	11.5	29.35	12	40.36	6	34.21	8	45.75
4278	9.5	27.14	11.2	36.87	12.5	32.01	13	41.18	7	36.25	8.5	46.48

Table 3.10 Shear parameters of pond ash, bottom ash and sand samples subjected to static compaction

Static stress in kJ/m^2	Pond ash				Bottom ash				Sand			
	Minimum dry density condition		Maximum dry density condition		Minimum dry density condition		Maximum dry density condition		Minimum dry density condition		Maximum dry density condition	
	C in kN/m^2	Φ in $(^0)$	C in kN/m^2	Φ in $(^0)$	C in kN/m^2	Φ in $(^0)$	C in kN/m^2	Φ in $(^0)$	C in kN/m^2	Φ in $(^0)$	C in kN/m^2	Φ in $(^0)$
0	4.5	22.42	7	30.43	6	25.04	6.5	33.02	5	26.86	6	40.03
400	5.6	23.26	8.5	31.49	6.5	26.42	7	33.65	5	27.47	6.5	41.77
1600	8.2	25.98	9	34.50	7	28.25	9	34.99	5.5	31.52	8	44.23
6400	8.9	27.69	9.6	35.46	8	29.89	10.5	37.32	6	33.16	8.5	46.12
25600	9.4	29.89	10.2	37.32	9	31.48	11	40.36	6.5	36.74	9	47.89

3.4 PERMEABILITY TEST ON MODEL FILTER BED

Model of filter is made up of transparent perpex sheet in circular shape of tank, having height 60 cm and diameter 35.5 cm. In which different set of permeability tests were done using of single sample and combination of different samples in various height. Using constant head permeability test method, coefficient of permeability of pure materials and combinations of materials were found out. For the sets of experiment 5 cm coarse aggrigates as filler material was given in base of the tank. Indivisually pure material like pond ash, bottom ash and sand were compacted in 15 cm height in the transparent tank to its 50 % relative density as in the field condition compaction of filter material on ash pond beyond 50 % not possible. Then water level is mantained in tank and coefficient of permeability of all filter materials were found out using constand head permeability method. In placed of water, fly ash water slurry in 1 : 4 ratio was supplied in the tank and their coefficient of permeability were found out. Similarly different combination of filter material like 5 cm of sand and either 10 cm of bottom ash and 10 cm of coarse pond ash were compacted upto 50 % of their relative density then coefficient of permeability were found out for both water and fly ash slurry. Also discharge of all samples, using Digital Nephelometric Turbidity Meter was found out. Coefficient of permeability of all the samples and turbidity are given in Table 3.11 and Table 3.12 respectively.

Fig.3.23 Filter Model containing samples

Table 3.11 Coefficient of permeability and turbidity of samples in water

Samples	Coefficient of permeability in cm/sec	Turbidity in NTU
Coarse Aggregate (5 cm) + Sand (15 cm)	0.209	0.8
Coarse Aggregate (5 cm) + Pond ash (15 cm)	0.0173	1.2
Coarse Aggregate (5 cm) + Bottom ash (15 cm)	0.0134	1
Coarse Aggregate (5 cm) + Sand (5cm) + Pond ash (10cm)	0.0183	1.8
Coarse Aggregate (5cm) + Sand (5cm) + Bottom ash (10 cm)	0.0152	1.1

Table 3.12 Coefficient of permeability of all sample in different time

Samples	Coefficient of permeability in cm/sec					
	1 min	2 min	5 min	10 min	30 min	60 min
Coarse Aggregate (5 cm) + Sand (15 cm)	3.937	2.494	1.478	0.778	0.731	0.726
Coarse Aggregate (5 cm) + Pond ash (15 cm)	5.784	2.398	1.398	0.953	0.876	0.865
Coarse Aggregate (5 cm) + Bottom ash (15 cm)	3.78	1.667	1.123	0.832	0.763	0.753
Coarse Aggregate (5 cm) + Sand (5cm) + Pond ash (10cm)	8.145	3.942	1.945	1.071	0.896	0.885
Coarse Aggregate (5cm) + Sand (5cm) + Bottom ash (10 cm)	4.008	1.779	1.208	0.904	0.775	0.763

Table 3.13 Turbidity of all sample in different time

Samples	Turbidity in NTU					
	1 min	2 min	5 min	10 min	30 min	60 min
Coarse Aggregate (5 cm) + Sand (15 cm)	5.1	3.1	2.2	1.2	1	1
Coarse Aggregate (5 cm) + Pond ash (15 cm)	13.4	11.8	9.2	7.6	5.4	5.2
Coarse Aggregate (5 cm) + Bottom ash (15 cm)	6.2	4.1	3.1	2.2	1.8	1.8
Coarse Aggregate (5 cm) + Sand (5cm) + Pond ash (10cm)	14.5	14	13.1	10.8	8.8	8.8
Coarse Aggregate (5cm) + Sand (5cm) + Bottom ash (10 cm)	7.1	6.2	5	4.5	3.3	3.1

CHAPTER-4

TEST RESULTS AND DISCUSSION

TEST RESULTS AND DISCUSSION

4.1 INTRODUCTION:

There are so many reasercher found out the geotechnical properties pond ash and bottom ash. But limited works have been done on the suitabilty of coarse pond ash and bottom ash as filter material. In these chapter a series of experiment have been done on geotechnical properties of coal ash and sand subjected to different loading intensity A permeabilty test on fiter model has been done. Also check whether coarse pond ash and bottom ash satisfy the IS Filter Criteria.

4.2 Index Properties:

The index properties of the materials i.e. specific gravity, plasticity characteristics and grain size distribution of pond ash, bottom ash and sand were determined as per Indian standard code of practice IS-2720 part (VI), IS-2720 part (III) and IS-2720 part (IV) respectively. The test results are presented in Table 1. Specific gravity of pond ash and bottom ash are found to be lower than that of the conventional earth material. The specific gravity of both the pond ash and bottom ash depend upon the source of coal, degree of pulverization and firing temperature. In addition to this the pond ash is subjected to mixing with other foreign matters in the ash pond which to some extent alters its specific gravity. Grinding of coal to higher fineness increases the specific gravity of pond ash and bottom ash due to breaking of cenosphere and carbon particles. The pond ash and bottom ash consists of grains mostly of fine sand to silt size. Based on the grain-size distribution, the coal ashes can be classified as sandy silt to silty sand. They are well graded with coefficient of uniformity of 3.33 and 3.52 for pond ash and bottom ash respectively and that of coefficient of curvatures are 1.2 and 1.028 respectively.

4.3 Grain size distribution:

Coal powder undergoes fusion during burning in addition to this it also undergoes flocculation and conglomeration in ash ponds. In this process a number of cenospheres joined together forming a porous matrix. As these samples are subjected to compaction energies they get separated and also get crushed. In the present experimental work both the ashes and sand were subjected to compacting energies of 149, 595, 1070, 2674 and 4278 kJ/m^3 and different compaction pressures of 400 kN/m^2 , 1600 kN/m^2 , 6400 kN/m^2 , 25600 kN/m^2. The gradation curve for the virgin sample and samples subjected to the above mentioned compacting energies and compacting pressure were determines and are presented in Fig. 3.1 & Fig. 3.2. As the both static and dynamic compaction increases particles gets either separated or crushed thus reducing their size. This is evident from the graph, as the curves shift more and more to the left with increase in both types of compaction. The coefficient of uniformity increases from 3.33 to 5.192 for pond ash and for bottom ash it increases from 3.52 to 5.79 with increase in compactive energy from zero to 4278 kJ/m3. Similarly coefficient of curvature increases from1.2 to1.9 for pond ash sample and for bottom ash sample 1.028 to1.392. For static compaction, the coefficient of uniformity increases from 3.33 to 4.38 for pond ash and for bottom ash it increases from 3.25 to 4.75 with increase in compaction pressure from zero to 25600kN/m^2. Similarly coefficient of curvature increases from1.2 to1.66 for pond ash sample and for bottom ash sample 0.83 to1.58. This indicates that with increase in compactive effort the size of grains reduced and the samples tend to be well graded. Similar test was done on sand sample subjected to both static and dynamic compaction and results are found like somewhat similar to that of coal ashes which are mention on above Tables 3.1 and 3.2. Variation of coefficient of uniformity and curvature of samples with both dynamic and static compaction are shown in fig. 4.1 and fig. 4.2 respectively.

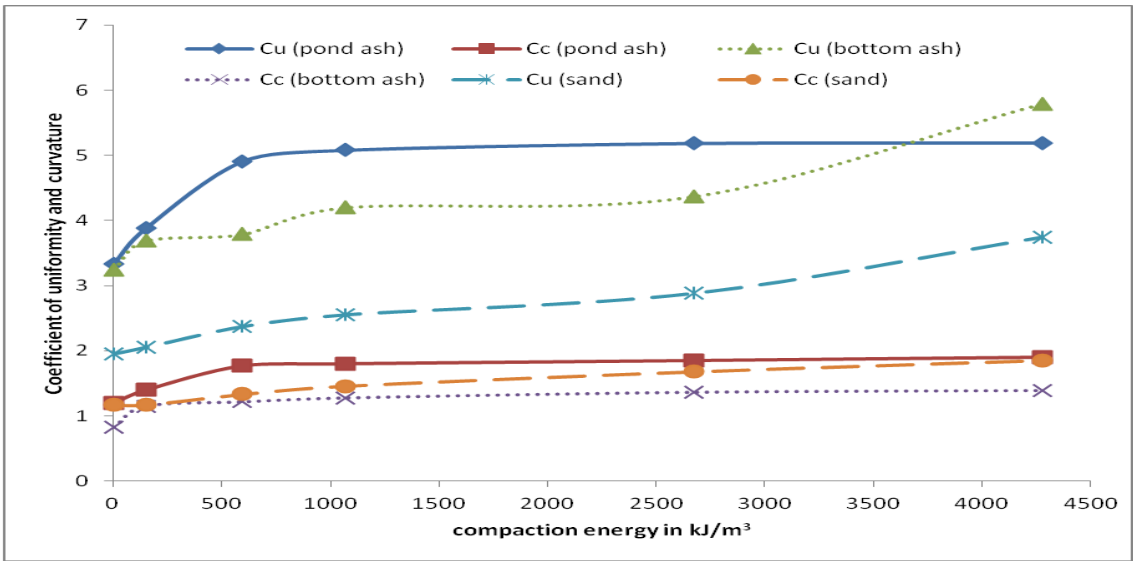

Fig.4.1 Coefficient of curvature and uniformity of samples subjected to different compactive energies

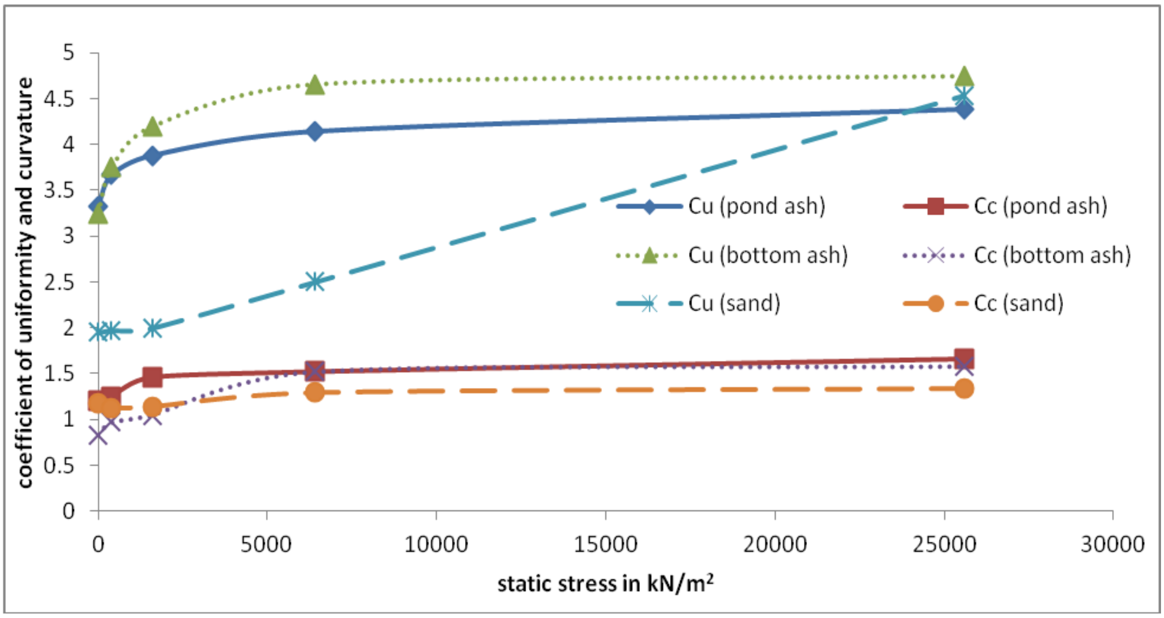

Fig. 4.2 Coefficient of curvature and uniformity of samples subjected to different static stresses

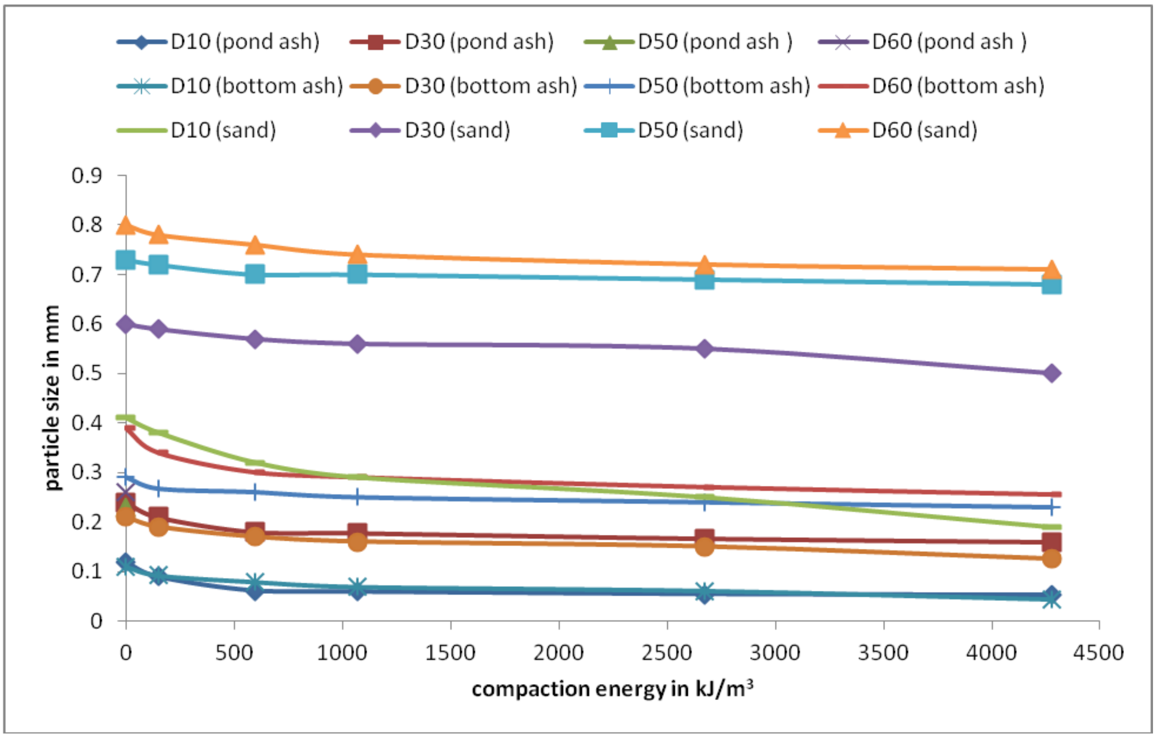

Fig. 4.3 Variation of particle size with compaction energy

4.4 Maximum and minimum dry density:

Maximum dry density means 100% relative density and that of minimum dry density means 0% relative density. As the compaction energy and static stress increases, minimum density and maximum density for coal ashes (pond ash and bottom ash) and sand increases. The variation of minimum density and maximum density of samples subjected to different compaction energy and static stress are given in Fig.4.5 and Fig.4.6. As stated earlier an increase in compactive energy and static stress results in an alteration of the particle size distribution. The samples, which are originally uniformly graded, became well graded when subjected to higher compaction. The change in gradation of particles helps in achieving a higher density.

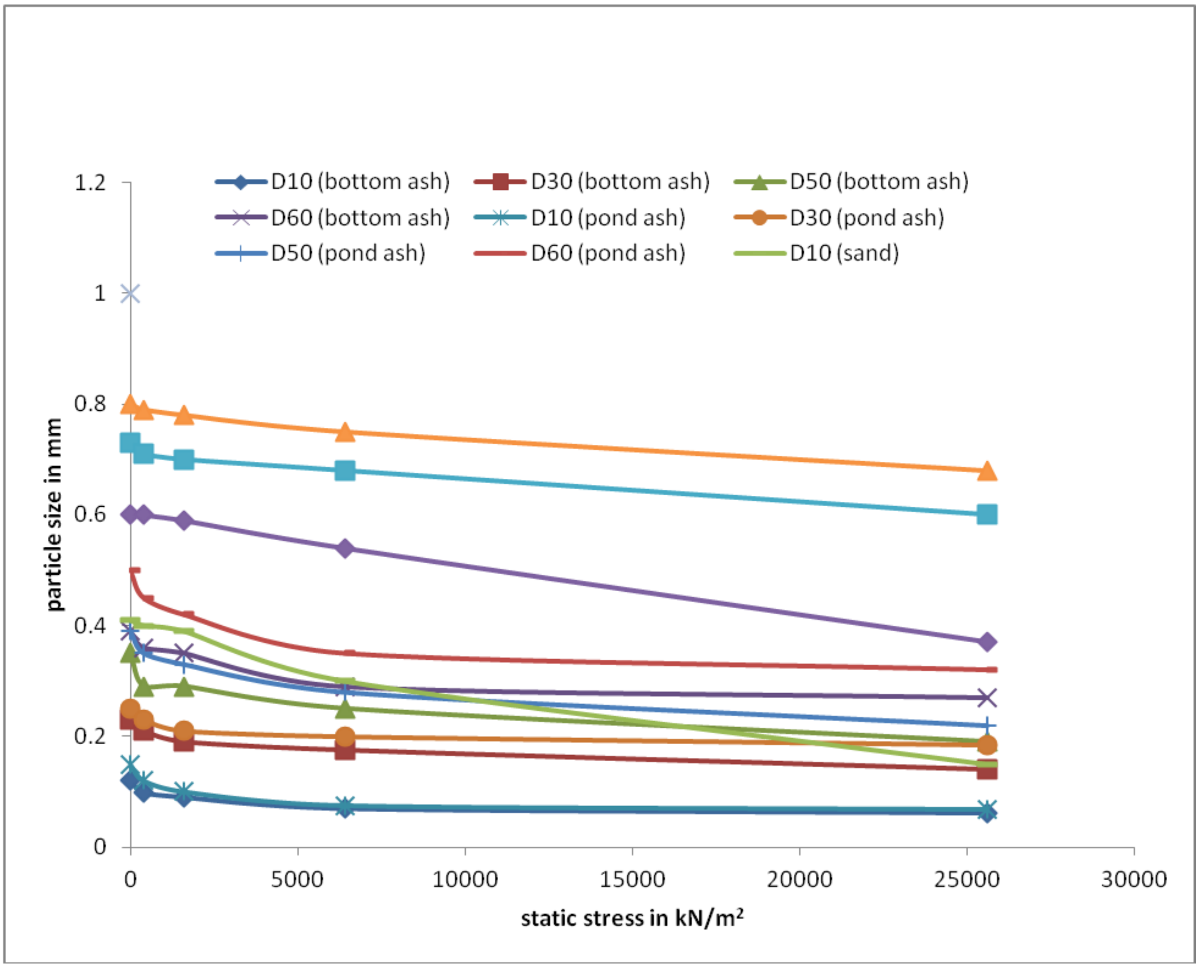

Fig. 4.4 Variation of particle size with static stress

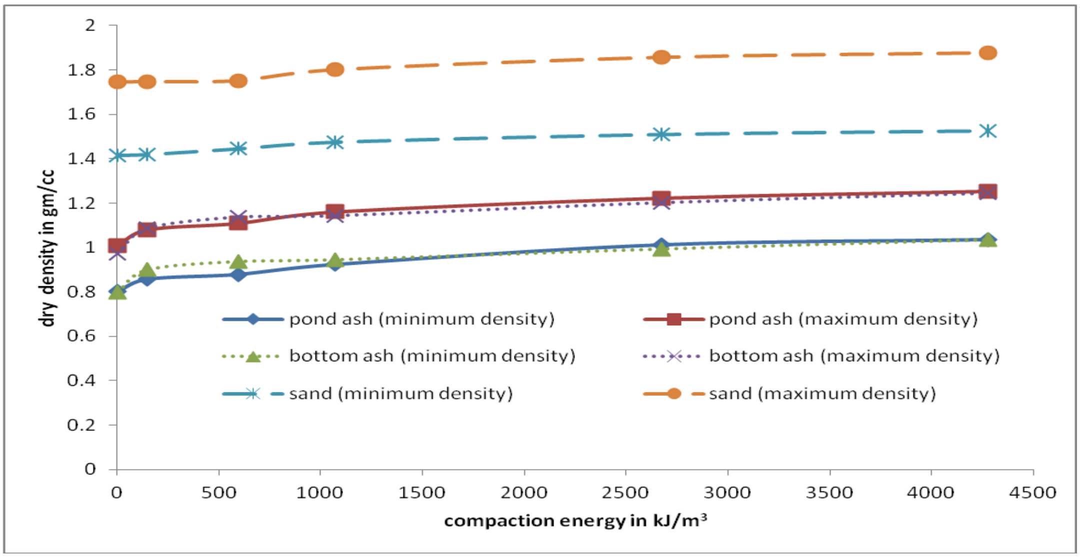

Fig. 4.5 Minimum and maximum density of samples subjected to different dynamic compactive energies

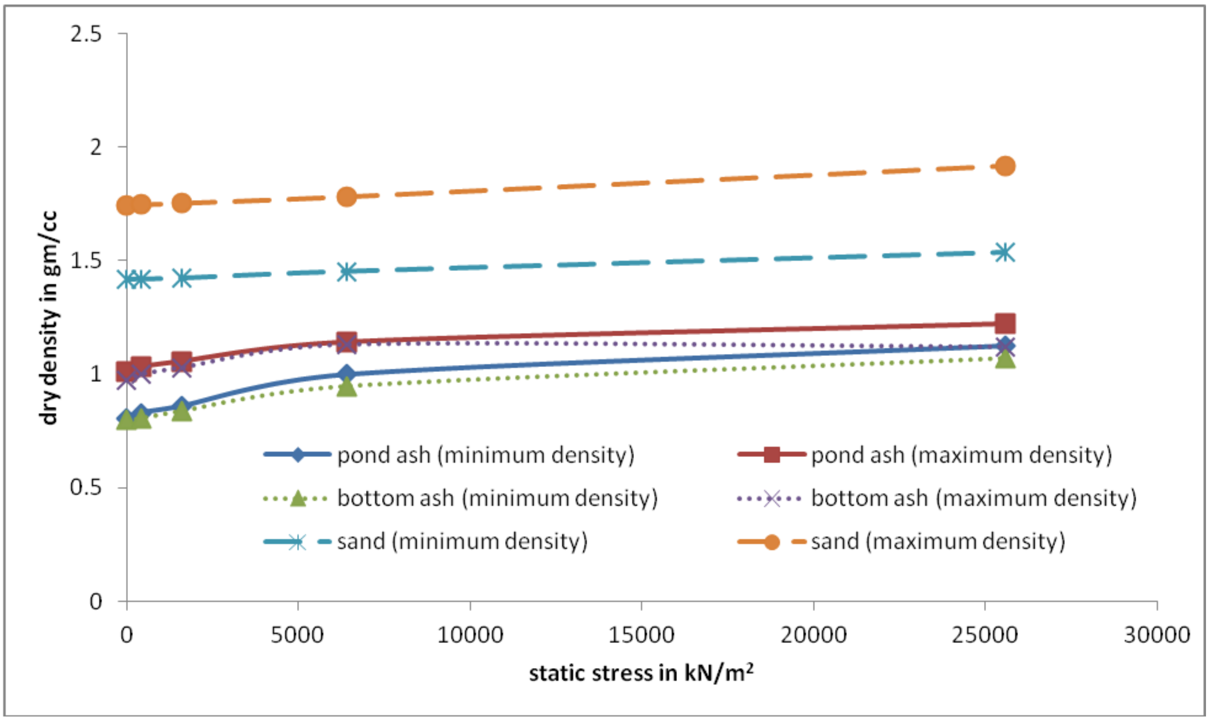

Fig. 4.6 Minimum and maximum density of samples subjected to different static stress

4.5 Permeability characteristics:

As the compaction energy and static stress increases, particles become finer and the gradation changes from a uniform gradation to well gradation. This is apparent from the change in gradation curves and the values of uniformity coefficient and coefficient of curvature. As the samples became well graded its maximum and minimum dry density increases compared to samples not subjected to any compaction. The variation of coefficient of permeability with compacting energy and static stress are shown in Fig.4.7 and Fig. 4.8. For pond ash sample permeability decreases up to 3 times in minimum dry density condition and decreases up to 6 times in maximum dry density condition as the compaction energy increases up to 4278kJ/m^3. Similarly as the compaction energy increases up to 4278kJ/m^3 for bottom ash sample permeability decreases up to 8 times in minimum dry density condition and that of 10 times in maximum dry density condition. For sand sample permeability decreases up to 1.2 times in minimum dry density condition and decreases up to 1.4 times in maximum dry density condition as the compaction energy increases up to 4278kJ/m^3. Somewhat similar patent of results are obtained when all samples pond ash, bottom ash, and sand are subjected to static stress. According to Allen Hazen (1911) the coefficient of permeability of soil is proportional to the square of a representative particle size. He proposed an empirical formula, $K=CD^2_{10}$, where C is constant varies from 0.4 to 1.2 with an average value of 1. Hence from the Fig.4.3 and Fig.4.4 found that sand is more permeable than coal ash.

4.6 Crushing Coefficient:

Both pond ash and bottom ash have large porous matrix due to flocculation and conglomeration of cenospheres particles occurs in ash pond. These particles are susceptible to crush under stress. The geotechnical property varies with static compaction only due to the crushing. The variation of crushing coefficient with confining pressure is given in Fig.4.9. At low load intensity crushing Coefficient for pond ash and bottom ash is lower than sand but at higher load intensity this is higher for coal ashes because this fused particles of ash show higher resistance to loading.

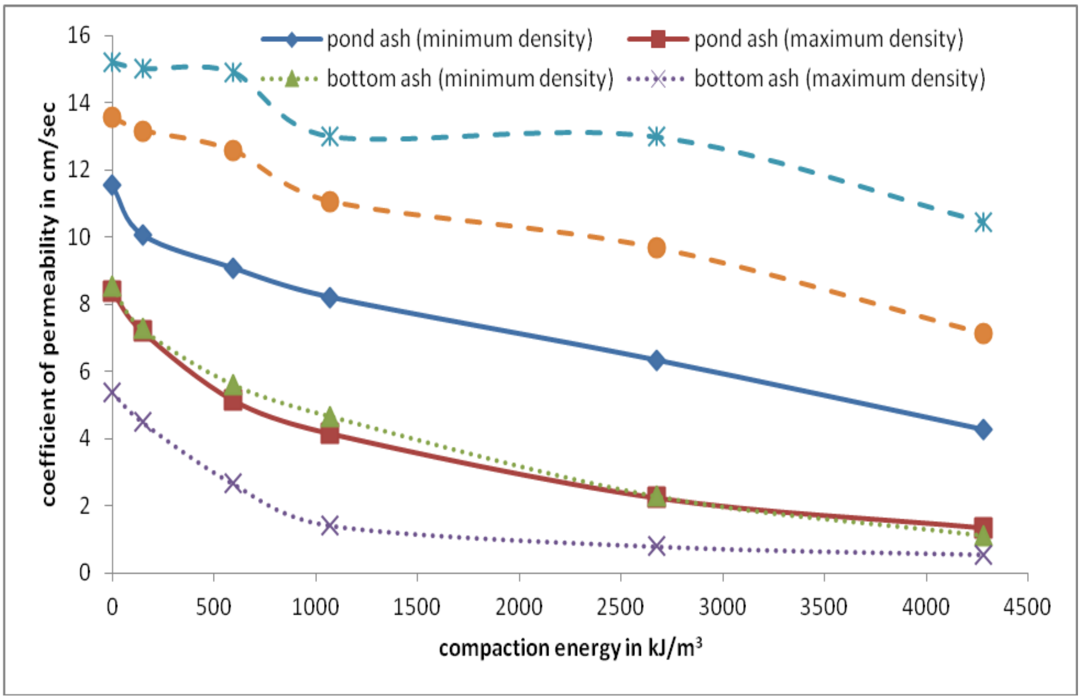

Fig 4.7 Variation of coefficient of permeability with compaction energy

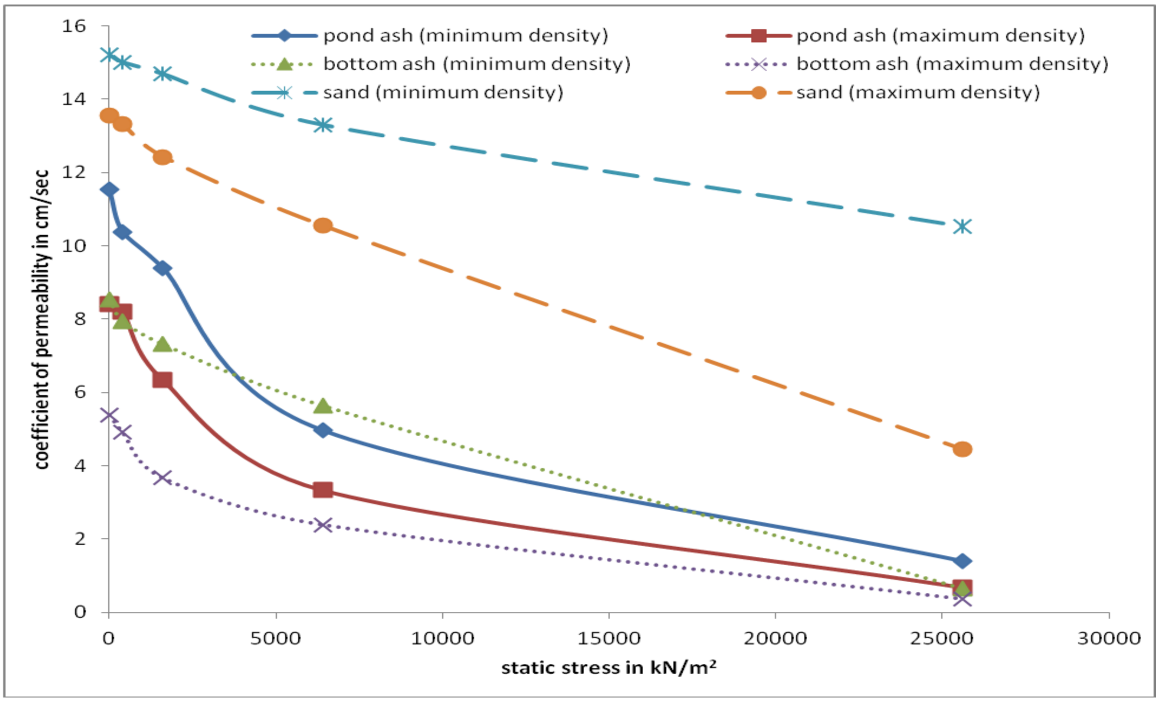

Fig 4.8 Variation coefficient of permeability with static copression stress

4.7 Shear Parameters:

The shear parameters of the crushed pond ash, bottom ash and sand specimens were determined at their minimum and maximum dry density. Plot between both compaction energy and static stress with unit cohesion and angle of internal friction are shown in Fig. 4.10, Fig.4.11, Fig. 4.12 and Fig. 4.13 respectively. This shows that the shear parameters of coal ash and sand depend on the density of the mass and the gradation of particles. Initially the rate of increase of unit cohesion with compaction energy and static stress is low followed by a sharp increase. Similar trend is also observed between the angles of internal friction with both compaction energy and static stress.

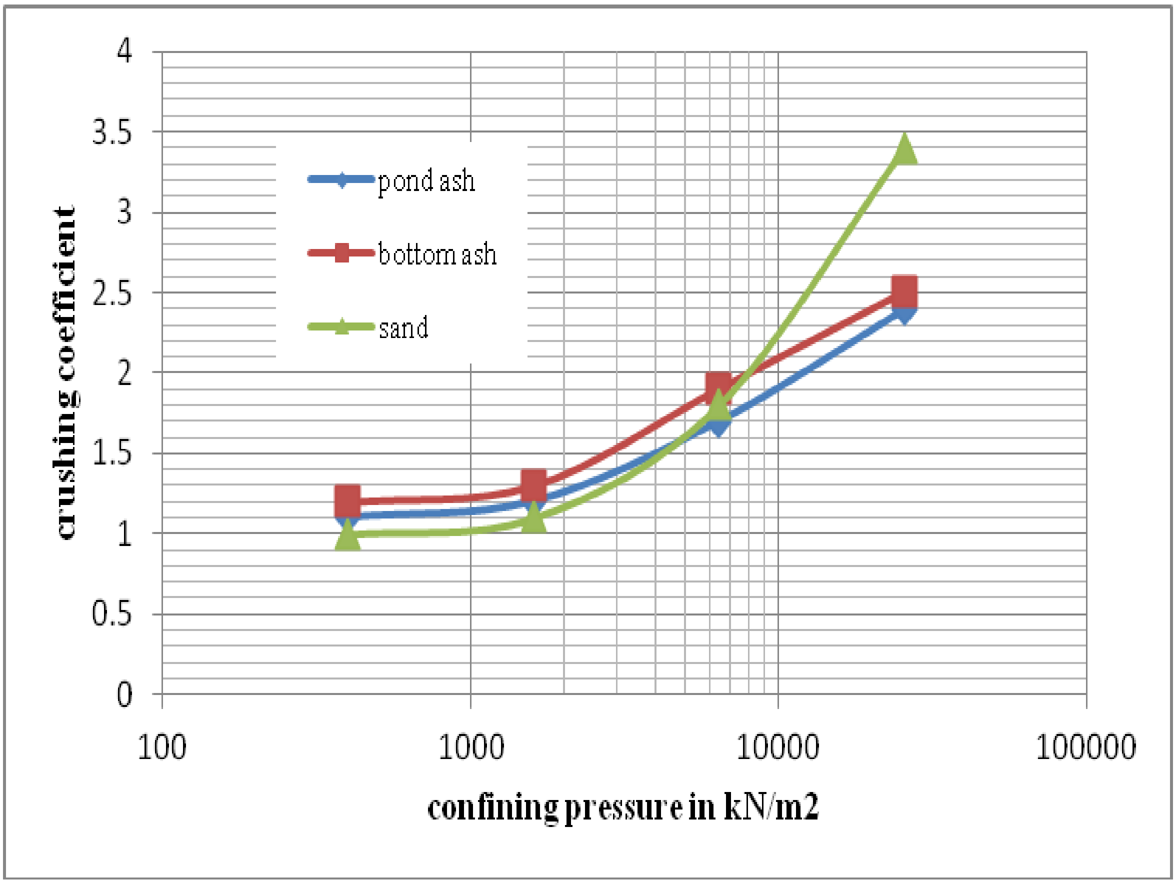

Fig. 4.9 Graph between crushing coefficient with confining pressure

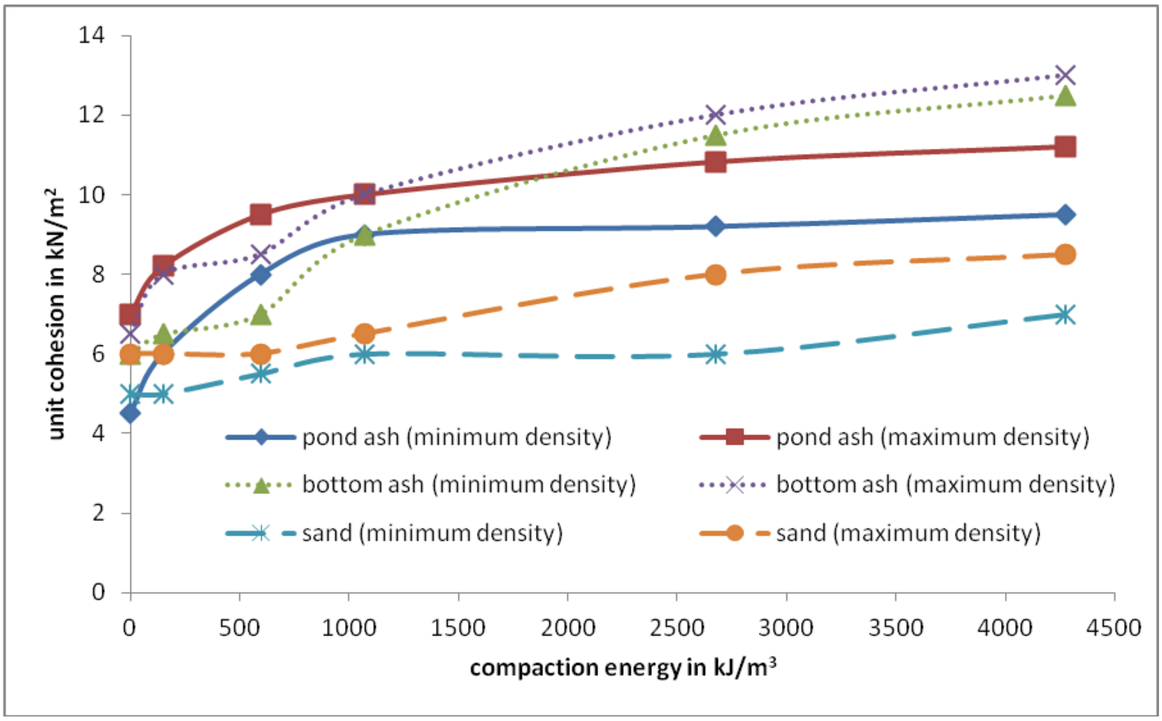

Fig. 4.10 Variation of unit cohesion of all the samples subjected to difeferent compaction energy

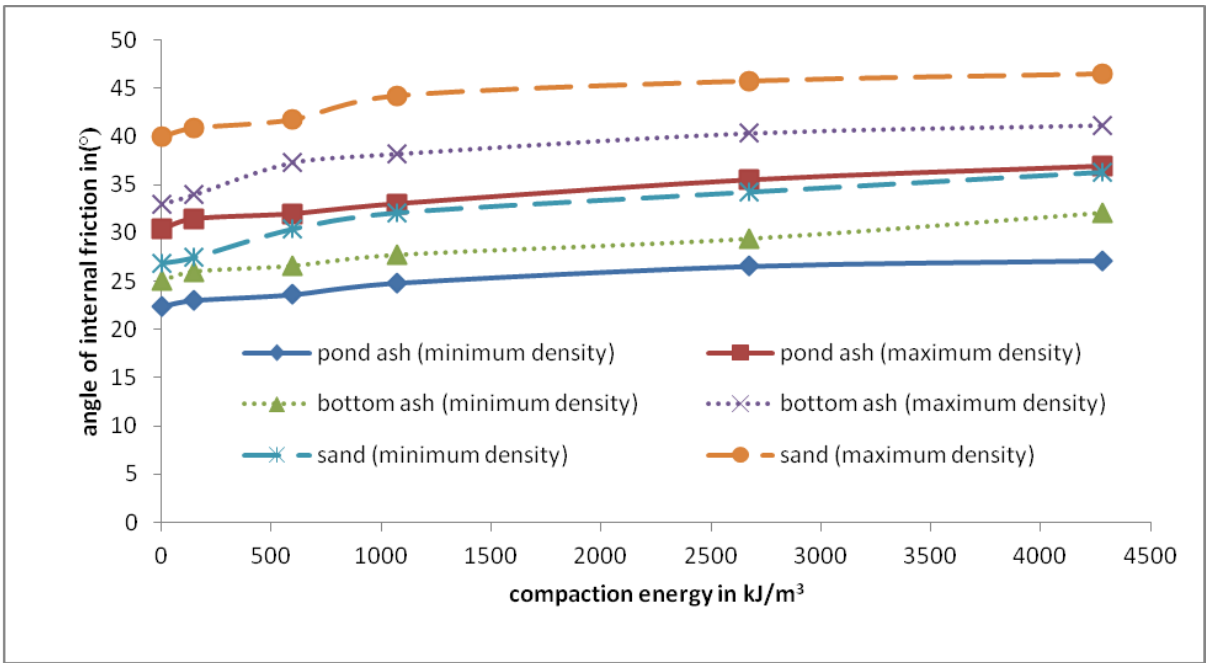

Fig. 4.11 Variation of angle of internal friction of all the samples subjected to difeferent compaction energy

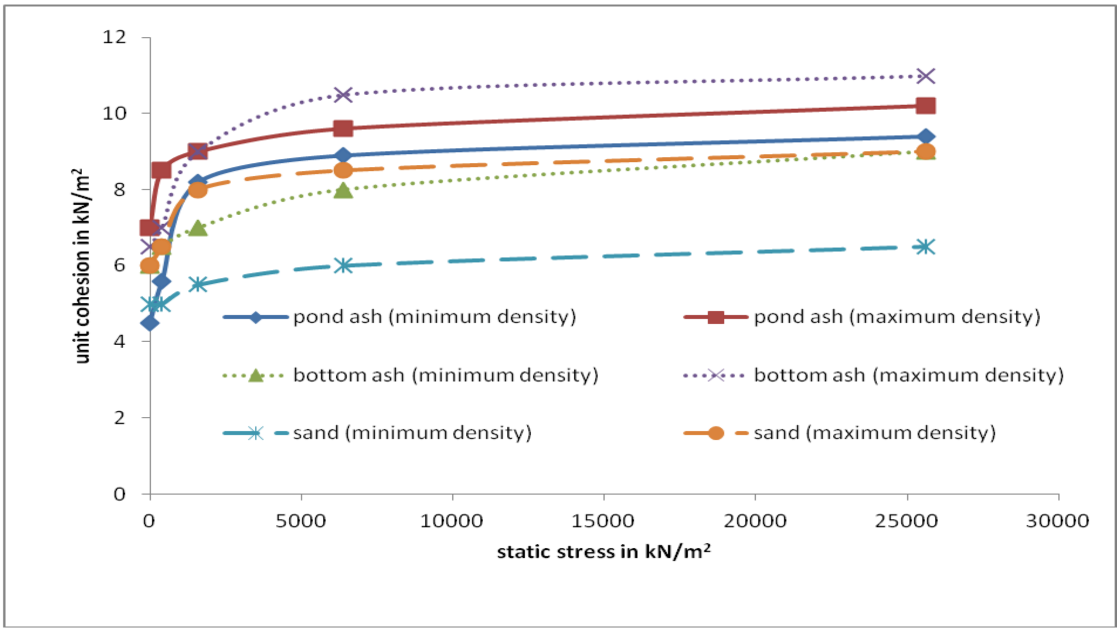

Fig. 4.12 Variation of unit cohesion of all the samples subjected different to static stress

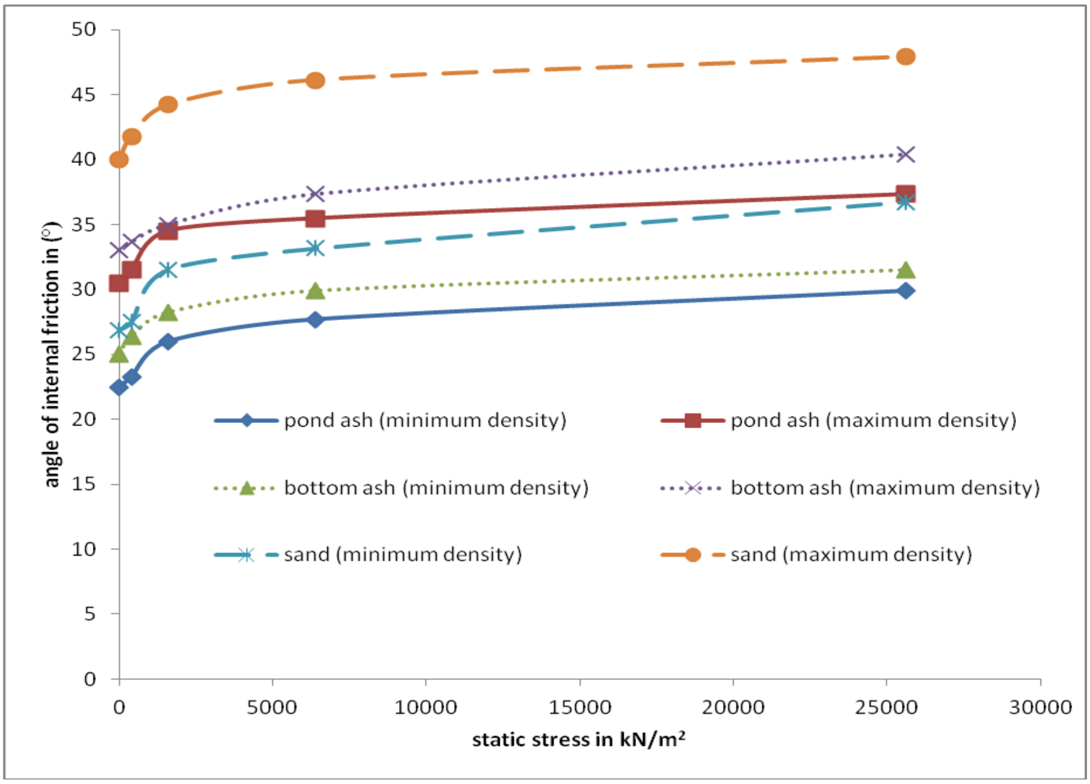

Fig. 4.13 Variation of angle of internal friction of all the samples subjected to static stress

4.8 RESULTS OF MODEL TEST

Coefficient of permeability of samples were determined in model test using constant head permeability test. In water coefficient of permeability for sand was found to be more whereas bottom ash was lowest. But in fly ash slurry coefficient of permeability of pond ash was found to be more than others two vergin samples. For layered samples in water coefficient of permeability of sand and bottom ash combined samples less than combined sand and pond ash sample. In case of layered sample similar result was found in fly ash slurry. In fly ash slurry permeability decreases with time only due to setteling of fly ash slurry. The variation of coefficient of permeability with time is shown in Fig. 4.14. It is found from the graph that after 10 min permeability remians nearly constant for all the samples. Different values of coefficient of permeability for all the samples are due to clogging. Clogging of samples depend on the gradation of paricles and their voids. Turbidity of all discharge slurry were determined by using Digital Neploturbidity Meter. It was found that turbidity value also decreases with time only due to clogging. The various of turbidity with time is shown in Fig.4.15 . More turbidity was found in pond ash sample because sand and pond ash can not retain the fly ash.

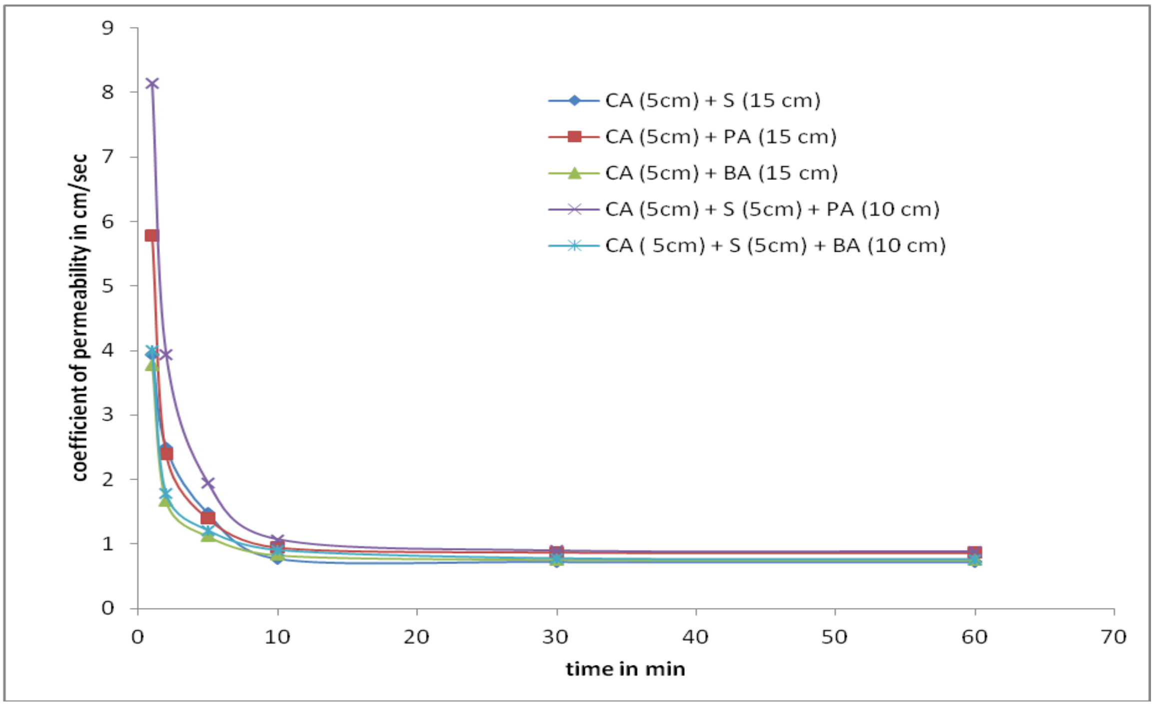

Fig. 4.14 Graph between coefficient of permeability and time

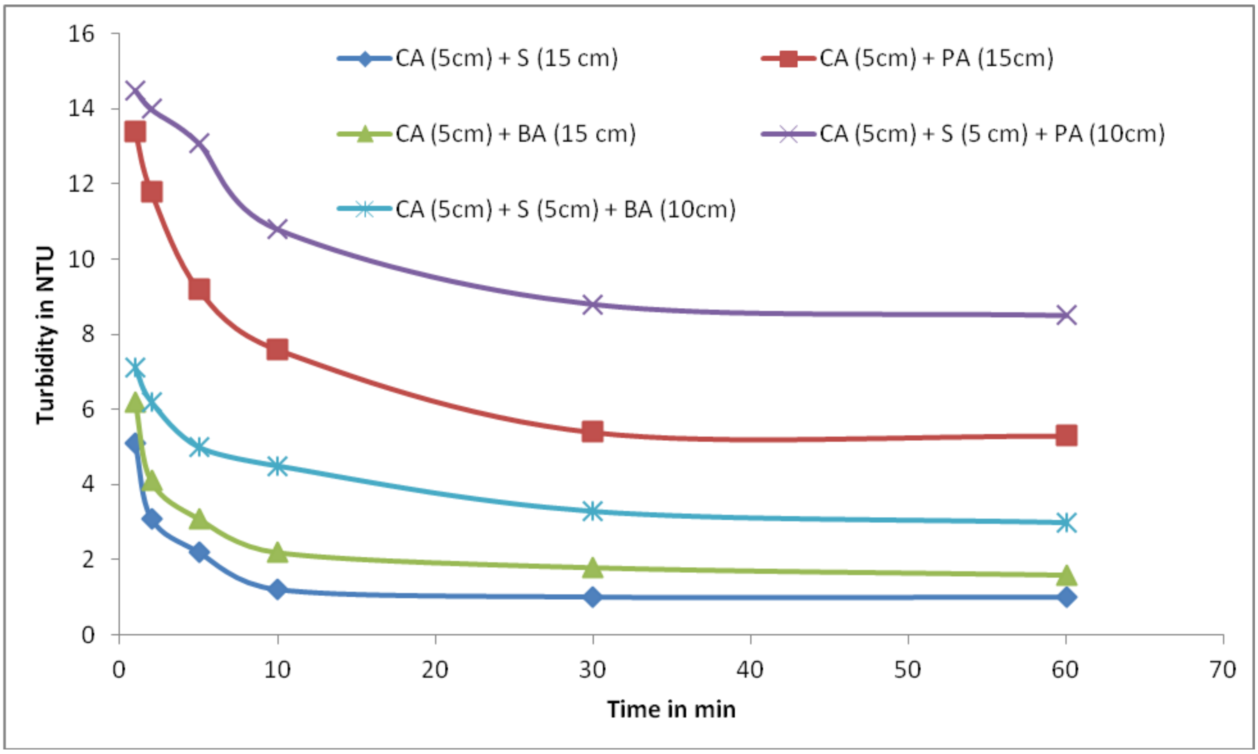

Fig. 4.15 Graph between turbidity and time

4.9 IS FILTER CRITERIA

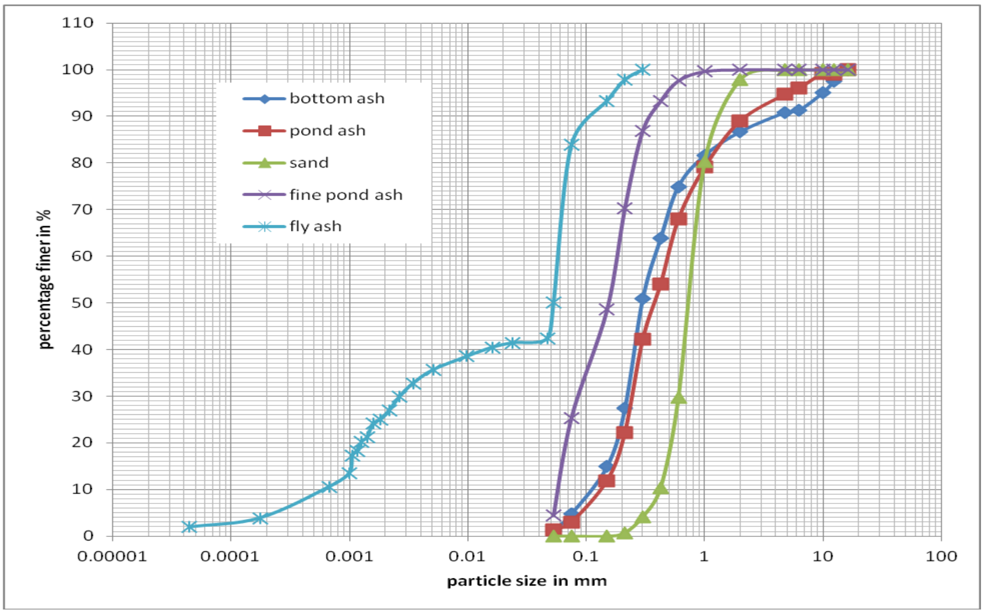

Fig.4.16 Grain size distribution curve of all virgin sample

Case-1: In first case coarse pond ash is taken as filter material and fly ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Tables

Filter Criteria as per Indian Standard (IS): 9429

<table>
<tr><td colspan="3">D15(F)/D 15(B) >5</td><td colspan="3">D15 (F) /D85(B) < 9</td><td colspan="3">D50(F)/D50(B) < 25</td><td colspan="3">Material passing 75 micron sieve is less than 5%</td></tr>
<tr><td colspan="3">Test Result</td><td colspan="3">Test Result</td><td colspan="3">Test Result</td><td colspan="3">Test Result</td></tr>
<tr><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td></tr>
<tr><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td></tr>
<tr><td>160</td><td>70</td><td>68</td><td>2.285</td><td>1.071</td><td>1.042</td><td>6</td><td>4.6</td><td>3.8</td><td>4.83</td><td>12.79</td><td>14.39</td></tr>
<tr><td colspan="3">Satisfying IS criteria</td><td colspan="3">Satisfying IS criteria</td><td colspan="3">Satisfying IS criteria</td><td colspan="3">Partially Satisfying IS criteria</td></tr>
</table>

Case-2: In second case bottom is taken as filter material and fly ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Table

<table>
<tr><td colspan="2">D15(F)/D 15(B) >5</td><td colspan="2">D15 (F) /D85(B) < 9</td><td colspan="2">D50(F)/D50(B) <25</td><td colspan="2">Material passing 75 micron sieve is less than 5%</td></tr>
<tr><td colspan="2">Test Result</td><td colspan="2">Test Result</td><td colspan="2">Test Result</td><td colspan="2">Test Result</td></tr>
<tr><td>Before</td><td>After crushing</td><td>Before</td><td>After crushing</td><td>Before</td><td>After crushing</td><td>Before</td><td>After crushing</td></tr>
</table>

crushing	dynamic compaction	static compaction	crushing	dynamic compaction	static compaction	crushing	dynamic compaction	static compaction	crushing	dynamic compaction	static compaction
130	70	67	1.142	1.1	0.97	6	4.4	4.2	2.97	9.01	11.90
Satisfying IS criteria			Satisfying IS criteria			Satisfying IS criteria			Partially Satisfy IS criteria		

Case-3: In third case sand is taken as filter material and fly ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Table

D15(F)/D 15(B) >5			D15 (F) /D85(B) < 9			D50(F)/D50(B) <25			Material passing 75 micron sieve is less than 5%		
Test Result			Test Result			Test Result			Test Result		
Before crushing	After crushing		Before crushing	After crushing		Before crushing	After crushing		Before crushing	After crushing	
	dynamic compaction	static compaction		dynamic compaction	static compaction		dynamic compaction	static compaction		dynamic compaction	static compaction
480	270	220	6.85	3.85	3.142	14.6	13.6	12	0	4.5	5.25
Satisfying IS criteria			Satisfying IS criteria			Satisfying IS criteria			Satisfying IS criteria		

Case-4: In fourth case fine pond ash is taken as filter material and fly ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Table

D15(F)/D 15(B) >5	D15 (F) /D85(B) < 9	D50(F)/D50(B) <25	Material passing 75 micron sieve is less than 5%
Test Result	Test Result	Test Result	Test Result
62	0.885	3	20
Satisfying IS criteria	Satisfying IS criteria	Satisfying IS criteria	Not Satisfy IS criteria

Case-5: In fifth case sand is taken as filter material and coarse pond ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Table

<table>
<tr><td colspan="3">D15(F)/D 15(B) >5</td><td colspan="3">D15 (F) /D85(B) < 4</td><td colspan="3">D50(F)/D50(B) <25</td><td colspan="3">Material passing 75 micron sieve is less than 5%</td></tr>
<tr><td colspan="3">Test Result</td><td colspan="3">Test Result</td><td colspan="3">Test Result</td><td colspan="3">Test Result</td></tr>
<tr><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td><td rowspan="2">Before crushing</td><td colspan="2">After crushing</td></tr>
<tr><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td><td>dynamic compaction</td><td>static compaction</td></tr>
<tr><td>3</td><td>1.687</td><td>1.375</td><td>6</td><td>3.375</td><td>2.75</td><td>2.43</td><td>2.26</td><td>2</td><td>0</td><td>4.5</td><td>5.25</td></tr>
<tr><td colspan="3">Satisfying IS criteria</td><td colspan="3">Partially Satisfying IS criteria</td><td colspan="3">Satisfying IS criteria</td><td colspan="3">IS criteria</td></tr>
</table>

Case-6: In sixth case sand is taken as filter material and bottom ash is taken as base material. As per the Indian Standard (IS): 9429 code of practice, following results are found which are given in Table

D15(F)/D 15(B) >5			D15 (F) /D85(B) < 4			D50(F)/D50(B) < 25			Material passing 75 micron sieve is less than 5%		
Test Result			Test Result			Test Result			Test Result		
Before crushing	After crushing		Before crushing	After crushing		Before crushing	After crushing		Before crushing	After crushing	
	dynamic compaction	static compaction		dynamic compaction	static compaction		dynamic compaction	static compaction		dynamic compaction	static compaction
3.69	2.076	1.69	6.4	3.375	2.75	2.43	2.26	2	0	4.5	5.25
Satisfying IS criteria			Partially Satisfying IS criteria			Satisfying IS criteria			Satisfying IS criteria		

CHAPTER-5

CONCLUSION

CONCLUSION

- Specific gravity of pond ash and bottom ash are found to be 2.18 and 2.12 respectively, which are lower than that of conventional earth material whereas specific gravity of sand is found to be 2.65

- As the dynamic compaction energy and static stress increases, particles crushed. The gradation changes from uniformly graded to well grade. Both pond ash and bottom ash are well graded whose coefficient of curvature values lies within 1 to 2 and coefficient of uniformity values lies within 3 to 5.

- Similarly as the compaction energy and static stress increases, gradation of sand sample also changes from uniformly graded to well grade but in very high load intensity it changes as compare to coal ash. It's coefficient of curvature values lies within 1 to 2 and coefficient of uniformity values lies within 1 to 4.

- Sample subjected to higher compaction energy became well graded. These samples show higher maximum dry density compare to virgin sample.

- After crushing due to both static and dynamic compaction, the coefficient of permeability of coal ash and sand samples decrease. Coefficient of permeability pond ash and bottom ash decreases with increase in loading intensity but lies within the range of sand.

- Strength parameters of coal ashes and sand subjected higher compaction energy and static stress are found to be higher when tested at their minimum and maximum densities. Both these samples possess little cohesion but the angle of internal friction is substantially high due to interlocking between particles.

- Particles crushed when these were subjected to different static stresses and their gradation changes from uniformly to well grade. At low load intensity crushing coefficient of coal ash is higher than sand but at very high load intensity crushing coefficient of sand is higher than coal ash.

- From the model test it was found that coefficient of permeability of all the virgin samples and layered samples decrease with increase in time due to settlement of fly ash slurry. After 60 min. values of coefficient of permeability of all samples are found to be same and do not change with time. So as per permeability criteria coarse pond ash and bottom ash can replace sand in filters.

- From the model test it was found that turbidity of all the virgin samples and layered samples decrease sharply with increase in time due to clogging of ash particles in the voids of coarse pond ash, bottom ash, and sand.

- It is found that coarse pond ash, bottom ash and sand used in the present study meets the filter criteria as per Indian standard of practice. After crushing in both static and dynamic compaction, it is found that all three samples coarse pond ash, bottom ash and sand used in the present study meets the filter criteria as per Indian standard of practice.

- Use of both coarse pond ash and bottom ash as a filter material also reduces the cost of construction of ash dyke. It is also an effective means of utilisation of thermal power plant waste.

CHAPTER-6

SCOPE FOR FURTHER STUDIES

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For effective functioning of coarse pond ash and bottom ash as filter material some more aspects have to be investigated

- Analysis of more geotechnical properties of coarse pond ash and bottom ash to find out their suitability as filter material.
- Liquefaction potential of coarse pond ash and bottom ash and stability of ash dyke.
- Clogging and Long term permeability of ash dyke
- Some more filter criteria
- The environment aspects arising out of the leachate from the ash dyke
- Prototype model study

CHAPTER-7
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